CRANFIELD UNIVERSITY

YASER YADEKAR

A FRAMEWORK TO MANAGE UNCERTAINTIES IN CLOUD MANUFACTURING ENVIRONMENT

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING

PhD THESIS
Academic Year: 2015 - 2016

Supervisors: Dr. Essam Shehab & Dr. Jörn Mehnen
October 2016

CRANFIELD UNIVERSITY

SCHOOL OF AEROSPACE, TRANSPORT AND MANUFACTURING

PhD THESIS

Academic Year 2015- 2016

YASER YADEKAR

A Framework to Manage Uncertainties in Cloud Manufacturing Environment

Supervisors: Dr. Essam Shehab & Dr. Jörn Mehnen
October 2016

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

ABSTRACT

This research project aims to develop a framework to manage uncertainty in cloud manufacturing for small and medium enterprises (SMEs). The framework includes a cloud manufacturing taxonomy; guidance to deal with uncertainty in cloud manufacturing, by providing a process to identify uncertainties; a detailed step-by-step approach to managing the uncertainties; a list of uncertainties; and response strategies to security and privacy uncertainties in cloud manufacturing. Additionally, an online assessment tool has been developed to implement the uncertainty management framework into a real life context.

To fulfil the aim and objectives of the research, a comprehensive literature review was performed in order to understand the research aspects. Next, an uncertainty management technique was applied to identify, assess, and control uncertainties in cloud manufacturing. Two well-known approaches were used in the evaluation of the uncertainties in this research: Simple Multi-Attribute Rating Technique (SMART) to prioritise uncertainties; and a fuzzy rule-based system to quantify security and privacy uncertainties. Finally, the framework was embedded into an online assessment tool and validated through expert opinion and case studies.

Results from this research are useful for both academia and industry in understanding aspects of cloud manufacturing. The main contribution is a framework that offers new insights for decisions makers on how to deal with uncertainty at adoption and implementation stages of cloud manufacturing. The research also introduced a novel cloud manufacturing taxonomy, a list of uncertainty factors, an assessment process to prioritise uncertainties and quantify security and privacy related uncertainties, and a knowledge base for providing recommendations and solutions.

Keywords: Cloud Technology, Cloud Manufacturing, Cloud Computing, Uncertainty, Uncertainty Management, Simple Multi-Attribute Rating Technique, Fuzzy rule-based system.

ACKNOWLEDGEMENTS

My gratitude is first and foremost to almighty Allah for his blessings and for granting me the will to achieve my goals in life

I would like to express my very great appreciation to my supervisors, Dr. Essam Shehab and Dr. Jörn Mehnen, for their continuous guidance and supervision throughout all stages of my research work at Cranfield University. I greatly appreciate their patience, and confidence in me.

My sincerest appreciation also goes to my beloved parents, my wife and son Salman, along with brothers, sisters, and step sisters, whose unconditional love has made it possible for me to count on them whenever I needed support.

I would also like to thank the members of CAPP-4-SMEs project that is supported by European Union 7th Framework Programme and other industry practitioners for their contributing in this research.

My deepest thanks to my colleagues at Cranfield University for their support and creative guidance which enabled me to overcome any obstacle that faced me at the beginning of my research journey.

Last but not at least, I would like to thank all my precious friends for their friendship, kindness, support, and the special time spent during my studies. I have been made to feel a part of a real family.

Yaser Mohammed Yadekar

LIST OF PUBLICATIONS

Journal Papers

1. Yadekar, Y., Shehab, E., and Mehnen, J. (2016), "Taxonomy and uncertainties of cloud manufacturing", *International Journal of Agile Systems and Management*, vol. 9, no. 1, pp. 48–66.
2. Yadekar, Y., Shehab, E., and Mehnen, J. (2016), "A Framework to Manage Uncertainties in Cloud Manufacturing", International Journal of Production Economics, To be submitted.
3. Yadekar, Y., Shehab, E., and Mehnen, J. (2016), "Uncertainty Quantification in Cloud Manufacturing", Robotics and Computer-Integrated Manufacturing, To be submitted.

Conference Papers

4. Yadekar, Y., Shehab, E., and Mehnen, J. (2015) "An Approach to Assess Uncertainties in Cloud Manufacturing" *In Transdisciplinary Lifecycle Analysis of Systems: Proceedings of The 22nd ISPE Conference on Concurrent Engineering*, TU Delft, Delft, Netherlands, 20-23 July 2015, Vol. 2, pp. 318-324. IOS Press. doi.org/10.3233/978-1-61499-544-9-318.
5. Yadekar Y, Shehab E and Mehnen J. (2014) "Uncertainties in Cloud Manufacturing" *Proceedings of the 21st ISPE Inc. International Conference on Concurrent Engineering*, , Beijing , China, 8-10 September 2014, pp. 297–306. IOS Press. doi.org/10.3233/978-1-61499-440-4-297.
6. Yadekar Y, Shehab E and Mehnen J. (2014) "A Taxonomy for Cloud Manufacturing" *Proceedings of the 12th International Conference on Manufacturing Research (ICMR 2014)*, Southampton Solent University, Southampton UK, 9-11 September 2014, pp. 103-108, ISBN 978-0-9926958-4-2, ISSN 2053-3373.
7. Yadekar Y, Shehab E and Mehnen J. (2013) "Challenges of Cloud Technology in Manufacturing Environment" *Proceedings of The 11th International Conference on Manufacturing Research (ICMR 2013),* Cranfield University, Cranfield UK, 19-20 September 2013, pp 177-182, ISBN 978-1-907413-23-0, ISSN 2053-3373.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AL	Artificial Intelligence
AM	Agile Manufacturing
ASP	Application service provider
BOA	Bisector of area
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CIA	Information security model called
CMAS	Cloud manufacturing application system
CNC	Computer Numeric Control
CSA	Cloud Security Alliance
COG	Centre of Gravity
CPU	Central processing unit
EMV	Expected monetary value
ENISA	European Network and Information Security Agency
EU	European Union
FIS	Fuzzy inference system
FRBS	Fuzzy rule-based system
IaaS	Infrastructure-as-a-Service
LOM	Last of maximum
IoT	Internet of Things
ISO	International Organization for Standardization
IT	Information Technology
MCDA	Multiple-criteria decision analysis
MCS	Monte-Carlo Simulation
MeOM	Mean of maxima
MGrid	Manufacturing Grid
MOM	Middle of maximum
NIST	National Institute of Standards and Technology

NM	Network Manufacturing
NUSAP	Numeral Unit Spread Assessment Pedigree
QoS	Quality of Service
PaaS	Platform-as-a-Service
PDFs	Probability density functions
PLC	production life cycle
RFID	Radio-frequency identification
SA	Sensitivity analysis
SaaS	Software-as-a-Service
SLA	Service Level Agreements
SMART	Simple Multi-Attribute Rating Technique
SMEs	Small and medium enterprises
SOAP	Standard Object Access Protocol
WSDL	Web Services Definition Language
XML	Extensible Markup Language

1 INTRODUCTION

1.1 Research Background

From craft production to agile manufacturing, manufacturing has become an ever more complex process, relying on many new technologies and advanced networks in response to changes in local, national, and international markets (Wang *et al.*, 2012; Valilai and Houshmand, 2013). The use of new technologies and networks are becoming critical success factors in any enterprise (Yadekar *et al.*, 2013). Enterprises are attempting to gain competitive advantage in global markets by using the latest technologies, along with advanced networks, to create collaboration (Huang *et al.*, 2013; Wang *et al.*, 2014; Zhang *et al.*, 2014).

The rapid growth of information systems and advanced network technologies has had a significant impact on business enterprises around the world. Manufacturing companies currently rely on many advanced network technologies, such as Agile Manufacturing (AM), Network Manufacturing (NM), and Manufacturing Grid (MG), to operate a single manufacturing task from the integration of widely distributed sources (Xu, 2012). These manufacturing networks enable collaboration and sharing of manufacturing resources between manufacturing units.

Although manufacturers benefit from the implementation of state-of-the-art network technologies in gaining advantage over competitors, there are problems in these existing network technologies that affect production within the manufacturing industry. Some of these problems include sharing of manufacturing resources, where the resources are centralised into the network but cannot be distributed through the network due to a lack of manufacturing services management in the network; and the inability to access the manufacturing hard resources (equipment) in the manufacturing network due to complications in transferring hard resources into the network (Laili *et al.*, 2012; Xu, 2012; Gao *et al.*, 2013).

Another problem is the difficulty of knowledge sharing between manufacturing units, suppliers, customers, and partners due to geographical dimension, countries' regulations, different operation systems, and the amount of data and complex processes in manufacturing (Valilai and Houshmand, 2013). The sharing of knowledge can provide development strategies in how to both enhance competitive advantage and understand manufacturing practices within the industry (Zhang and Jin, 2012).

To address these problems affecting the manufacturing industry, a new manufacturing model that combines innovative technologies and existing manufacturing networks has emerged to create a new concept called "Cloud Manufacturing" (Li and Mehnen, 2013). This model can provide and share manufacturing resources and manufacturing capabilities as services to the users in business (Laili *et al.*, 2012). The cloud manufacturing model is complex and involves many advanced technologies and networks that need to be integrated efficiently (Luo *et al.*, 2013), and it provides the ability to exchange data and share knowledge among the different users across different enterprises and regions (Ren *et al.*, 2014). Figure 1-1 shows the cloud manufacturing model.

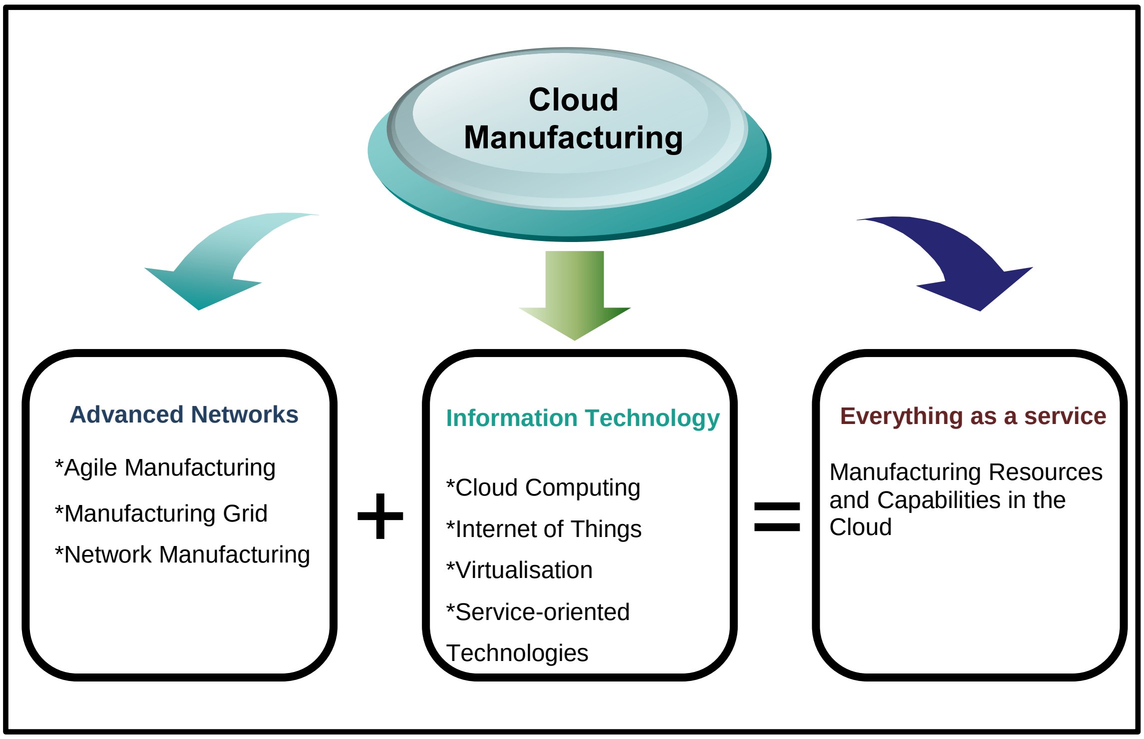


Figure 1-1: Cloud manufacturing model

Cloud manufacturing can be a major factor to reduce costs, maximise productivity, and increase business agility and innovation (Ren *et al.*, 2014), as well as facilitating the whole life cycle of manufacturing, providing safe, reliable, high-quality, cheap and on-demand manufacturing services (Zhang *et al.*, 2014). Cloud manufacturing also has the potential to exceed expectations with the right implementation. Moreover, cloud manufacturing can change and restructure manufacturing systems in the manufacturing industry, and move the manufacturing industry from production-oriented manufacturing to service-oriented manufacturing (Xu, 2012).

The production-oriented manufacturing concept is that of a mass production strategy, which produces massive amounts of standardised products for the market. This approach allows the enterprise to reduce costs and maximise profits. An example of production-oriented manufacturing is Henry Ford's mass production assembly line for the Ford Model T car. With the service-oriented manufacturing concept, the enterprise offers the customer both physical products and services together (Gao *et al.*, 2011). This strategy allows customers to be involved in the entire product manufacturing process, which includes design, manufacturing and sales (Gao *et al.*, 2009).

Cloud manufacturing concept is to integrate existing manufacturing technologies and new computing technologies so as to distribute manufacturing resources and capabilities between manufacturing units and divisions. Cloud manufacturing transforms and encapsulates manufacturing physical resources and manufacturing capabilities into a cloud by using technologies such as cloud Computing, Internet of Things (IOT) and virtualisation. Then, cloud manufacturing provides those manufacturing resources and manufacturing capabilities as services through an existing manufacturing network, for the users.

The rapid growth of advanced capabilities in Information Technology (IT) has allowed the manufacturing industry to apply new, complex manufacturing systems based on advanced networks and new computing technologies. So far though, industry has been hesitant in the uptake of new manufacturing paradigms, such as cloud manufacturing, due to a lack of understanding of the related uncertainties. The importance of understanding and managing uncertainties in cloud manufacturing can help businesses to design, operate, and implement cloud manufacturing to fully utilise its benefits.

1.2 Research Motivation

Manufacturing industry is changing quickly because of the rapid growth of advanced technologies in information systems and networks, which allow for collaboration around the world. Also, there is an ever increasing demand to provide service-oriented manufacturing, distribute manufacturing resources and capabilities, and increase productivity. According to a European Commission survey conducted in 2012, 80% of organisations that adopt cloud computing technology have reduced their costs by 10-20%. They have also enhanced mobile working (46%), productivity (41%) and standardisation (35%), as well as increased new business opportunities (33%) and markets (32%) (European Commission, 2012).

The transformation of existing manufacturing systems to new advanced and sophisticated systems, such as cloud manufacturing, that incorporate many state-of-the-art technologies, can be a big challenge for any enterprise. This transformation creates uncertainties in the new system that can impact upon design, implementation and operation of the manufacturing model.

Any chosen system must have the capability to perform in an uncertain environment (Koh and Saad, 2006), where technical, political, economic and other factors can be issues in an uncertain environment. So, there is a need to understand and tackle the uncertainties in cloud manufacturing. To address this issue, steps needed to be followed include: understand and define cloud manufacturing; identify and manage the uncertainties in cloud manufacturing; and develop a framework to manage uncertainty in cloud manufacturing.

1.3 Research Scope

The research focused on identifying cloud manufacturing and its characteristics and types. It involved detecting and evaluating uncertainties in cloud manufacturing at the adoption level, as well as the implementation level, within small and medium enterprises (SMEs). Due to the novel nature of the research that concerns the new research field of cloud manufacturing, and the associated lack of cloud manufacturing literature, the Author interacted with professionals within manufacturing, Information Technology, cloud technology, and academia for data collection. Moreover, this research concentrated only on the role of uncertainties in cloud manufacturing that related to management issues.

This research was limited to small and medium enterprises (SMEs) due to the importance of SMEs in economic terms: they represent 99% of businesses in the European Union (EU). In fact, with more than 20 million SMEs in Europe, two out of three private sector jobs are provided by SMEs, and they contribute more than half of the total value added by businesses in the EU. Without doubt, SMEs have a fundamental role in economic growth, innovation, employment and social integration (European Commission, 2013). The adoption of cloud manufacturing can help SMEs enter new markets and gain competitive advantage against other global competitors by providing solutions to limited resources. Implementation can also reduce IT infrastructure costs and allow enterprises to concentrate on their strategies and core business.

1.4 Research Aim and Objectives

The research aim is to develop a framework to manage uncertainty in cloud manufacturing for small and medium enterprises (SMEs). The framework comprises a cloud manufacturing taxonomy; a process to identify uncertainties; a list of uncertainty factors; a process to determine and rank the importance of each identified uncertainty; a process to quantify security and privacy uncertainty factors; and an assessment software tool.

The overall objectives are to:

1. Capture requirements for cloud manufacturing and its types, characteristics and attributes;
2. Develop a process to identify uncertainties in cloud manufacturing for SMEs;

3. Develop a framework and its software tool to assess and manage the uncertainty in a cloud manufacturing for SMEs;
4. Validate the proposed framework through case studies and expert opinion.

1.5 Industrial Collaboration

The EU-funded CAPP-4-SMEs project and three organisations were participated in this research through the development of framework and its validation. The CAPP-4-SMEs Consortium is comprised of 11 partners (4 universities, 1 multi-national manufacturing company and 6 SMEs) from 5 European countries (Sweden, UK, Greece, Germany and Spain). The three organisations were from different industries. The first organisation is a manufacturing company that provides a range of services in the area of CAD/CAM programming. The second organisation is a government organisation that provides services for infrastructure maintenance. The third organisation is a military organisation that responsible for accommodating the various needs of the armed forces and other military sectors.

1.6 Thesis Structure

The thesis is divided into eight chapters as shown in Figure 1-2. Chapter (1) provides a background and general overview of the research project, followed by an introduction of the research motivation, research scope, research aim and objectives, and industrial collaboration. The first chapter also outlines the remaining chapters of the thesis.

Chapter (2) provides reviews of literature on two main concepts: cloud manufacturing and uncertainty. In phase one of the literature review, the focus was on cloud manufacturing and its types, characteristics and attributes. In phase 2 the focus was on understanding uncertainty, and exploring the role of uncertainty in manufacturing and its effects in the cloud environment. Phase 2 also demonstrates uncertainty assessment methods and identifies the research gap.

Chapter (3) illustrates the research methodology developed to achieve the research aim and objectives. This chapter contains the key elements for the formulation of the research methodology: these are research approach, research purpose, data collection methods, and methodology phases.

Chapter (4) provides a better understanding of cloud manufacturing by exploring the concept of cloud manufacturing, measuring industrial awareness, capturing requirements and identifying the challenges concerning cloud manufacturing. This chapter also delivers a taxonomy for cloud manufacturing that helps in identifying characteristics and attributes, and captures requirements for cloud manufacturing and its types.

Chapter (5) develops a framework to manage the uncertainty in cloud manufacturing. This chapter begins by introducing and explaining the phases of development of the framework. It then explores the process of identifying uncertainties in the framework through interviews, Delphi technique, survey, brainstorming, and documentation reviews (academic and published technical reports).

Chapter (6) explains the process of assessing identified uncertainties by applying two methods of uncertainty assessment: Simple Multi-Attribute Rating Technique (SMART) to determine and rank the importance of each identified uncertainty in the cloud manufacturing; and a fuzzy rule-based system to quantify security and privacy uncertainty factors. Furthermore, a knowledge base that provides strategies and solutions to deal with security and privacy related uncertainty factors in cloud manufacturing was constructed.

Chapter (7) presents the software assessment tool development process, and validates the framework through case studies and experts. The tool includes a list of uncertainties, analysis and assessment of uncertainties, uncertainties ranking, and strategies and solutions for security and privacy related uncertainty factors in cloud manufacturing.

Chapter (8) summarizes the results, draws conclusions, and makes recommendations for future work. This chapter presents outcomes form this research that includes the research contribution to knowledge, research limitations, and future work. Also, it reveals answers to the research aim and objectives, and presents the overall research conclusion.

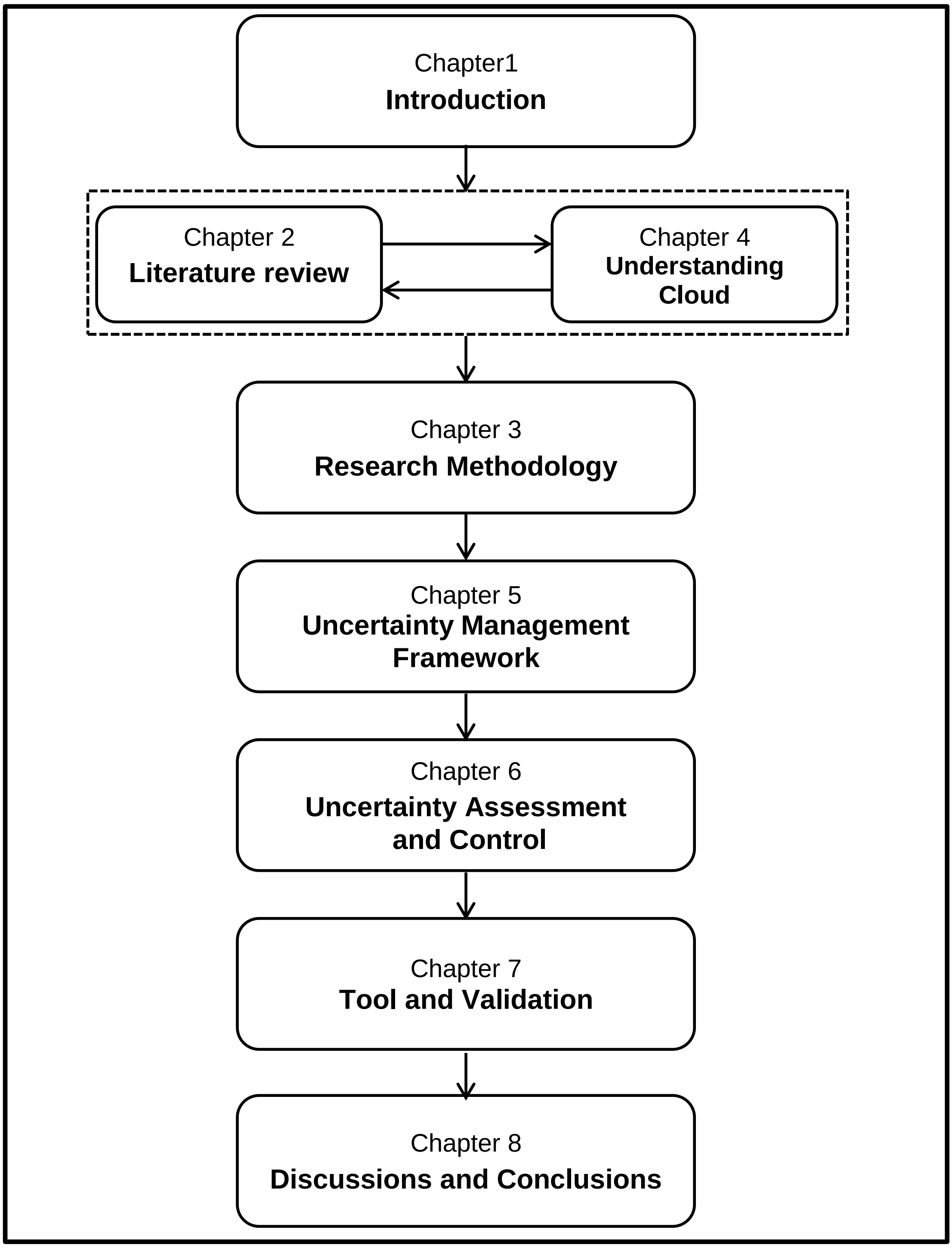


Figure 1-2: Thesis structure

2 LITERATURE REVIEW

2.1 Introduction

The role of technology in the manufacturing industry has become a critical factor and it is fundamental in supporting technical and business processes. Today, the emergence of new technologies such as cloud computing, Internet of Things, virtualisation, and Web services, with the help of existing advanced manufacturing networks, can shift the manufacturing industry from production-oriented manufacturing to services-oriented manufacturing. The combination of innovative technologies and existing manufacturing networks has created a new concept, called “cloud manufacturing”.

The aim of this chapter is to provide a comprehensive review in area of cloud manufacturing and uncertainties in order to understand the research aspects and identify the research gap. In a view to understand the context of this research project, the literature review focuses on two main concepts, namely: cloud manufacturing and uncertainty. The search in academic database engines was limited to keywords related to the research topics. Figure 2-1 shows the literature review topic diagram.

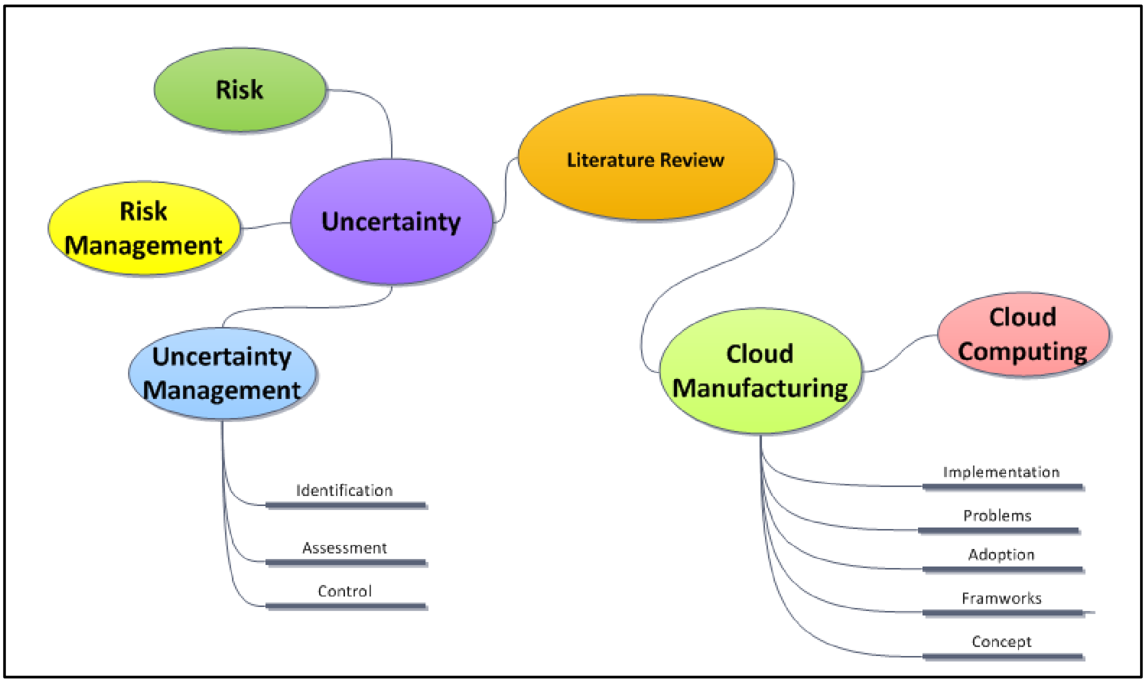


Figure 2-1: Literature review areas

In first part of literature review, the focus was on cloud manufacturing and its types, characteristics, and attributes. The results from this phase are as follows:

- Understand the cloud manufacturing concept by exploring various definitions of cloud manufacturing.
- Illustrate latest cloud manufacturing frameworks.
- Identify cloud manufacturing adoption factors.
- Demonstrate cloud manufacturing challenges.
- Present current implementation of cloud manufacturing.

While in second part, focus was on understanding uncertainty, exploring the role of uncertainty in manufacturing and its effects in the cloud environment. The results from this phase are as follows:

- Differentiate between uncertainty and risk.
- Present uncertainty management.
- Understand the role of uncertainty (location and level).
- Cover uncertainty assessment methods
- Develop an initial list of uncertainty factors in cloud manufacturing

The structure of the chapter is divided into six sections. The first section explains the review process (section 2.1). Next sections, introduces cloud computing technology (section 2.2) and defines cloud manufacturing (section 2.3). Then, section 2.4 examines the concept of uncertainty and risk. The fifth section presents the research gap findings. Finally, section 2.6 summarises the previous sections. Figure 2-2 shows the chapter structure.

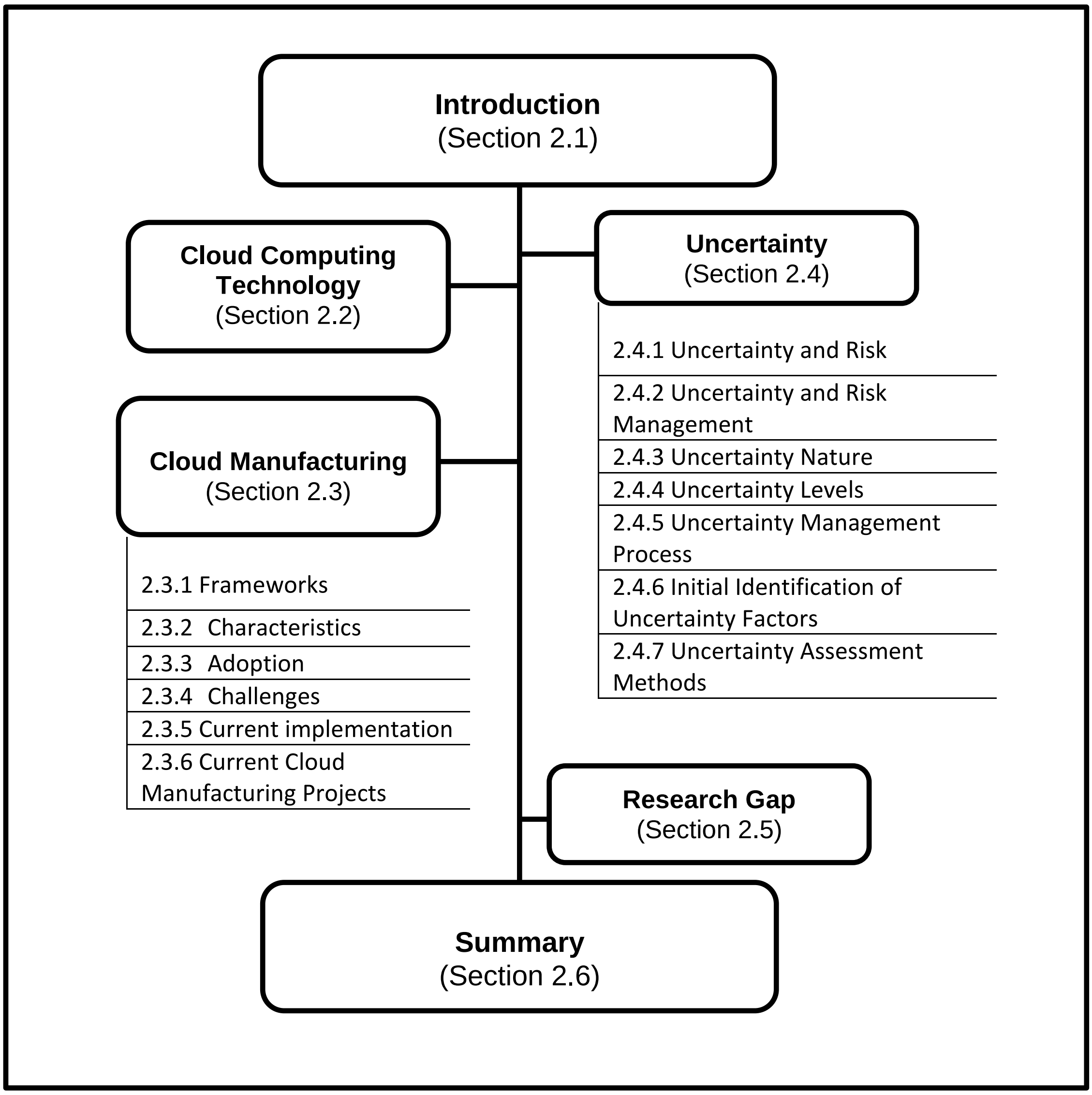


Figure 2-2: Chapter structure

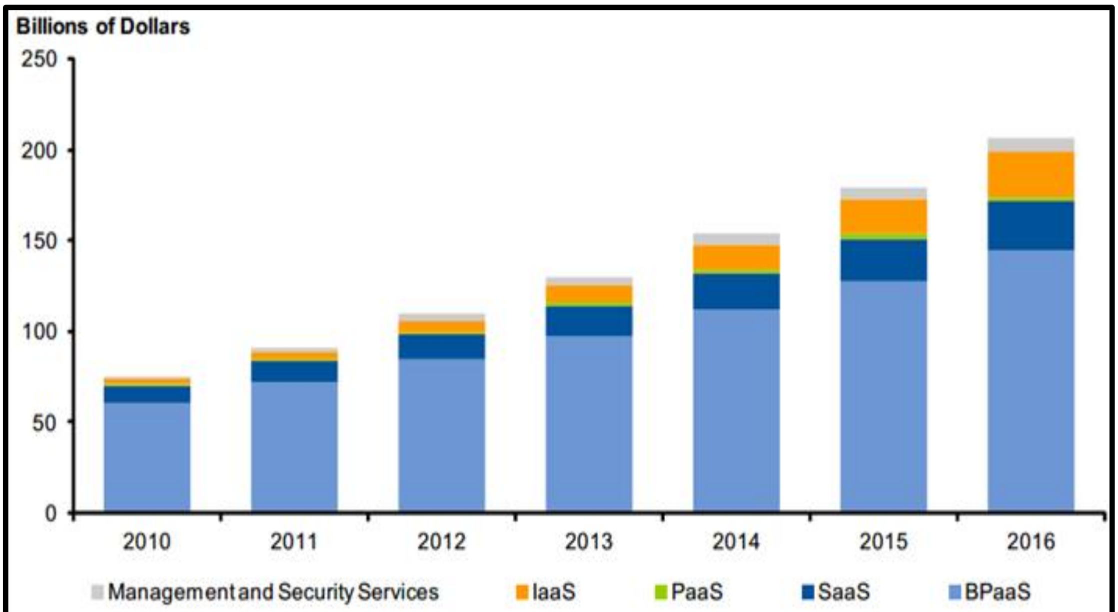
2.2 Cloud Computing Technology

The cloud computing technology concept has led to many changes in the Information Technology industry in the way services are invented, developed, deployed, scaled, updated, maintained and ultimately paid for (Marston *et al.*, 2011).

There are a variety of definitions for cloud computing technology; a generic description was given in 2011 by the National Institute of Standards and Technology (NIST) (Mell and Grance, 2011). NIST define cloud computing technology as follows: “cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models".

The roots of cloud computing technology can be traced back to four technologies: hardware (virtualisation, multi-core chips); Internet technologies (Web services, service-oriented architectures, Web 2.0); distributed computing (clusters, grids); and systems management (autonomic computing, data centre automation) (Voorsluys *et al.*, 2011). In hardware, virtualisation technology creates multiple computing resources, such as processors, memory and I/O devices in a single physical platform. This allows sharing and running many computing resources into the cloud. Cloud computing's second technological requirement is the Internet technologies that made it possible to: operate software applications on different platforms; link more than one software application together; and provide the ability to access software applications over the Internet. The third technology of cloud computing is distributed computing, which allows accessing distributed resources on the grid network in the least possible time, as well as applying the utility billing method, "pay-per-use", for charging the use of distributed resources through the grid network. The last technology is automation, which allows for the operating and managing of data centres without the need for human interaction.

An increase in demand for cloud computing services has enabled the cloud computing industry to become a high growth industry in the Information Technology sector. According to Gartner Inc. in 2010 (Pring *et al.*, 2010), the cloud computing market will grow to reach $148.8 billion in 2014. Figure 2-3 shows Gartner's prediction for the public cloud services market from 2010 until 2016.



***Key: IaaS** = Infrastructure-as-a-Service, **PaaS** = Platform-as-a-Service
SaaS = Software-as-a-Service, **BPaaS** = Business Process as a Service

Figure 2-3: Public cloud services market size (Gartner 2012)

The relationship between traditional computing devices and cloud computing technology can provide a better understanding of this new technology (Yadekar *et al.*, 2013). As Figure 2-4 shows that there are three main elements in a traditional computing device: hardware, operating system, and software applications. Each item has a particular role in the computing device. The hardware consists of a central processing unit (CPU), input and output devices, a storage unit, and network capability. The CPU is responsible for all operations in the computing device, and the network capacity is for connecting the device to the network and joining other computing devices to the network. The operating system is a set of software programs to manage the application, and to control hardware devices in the computing device. The third element is software applications that exist in the computing device to perform tasks for the users.

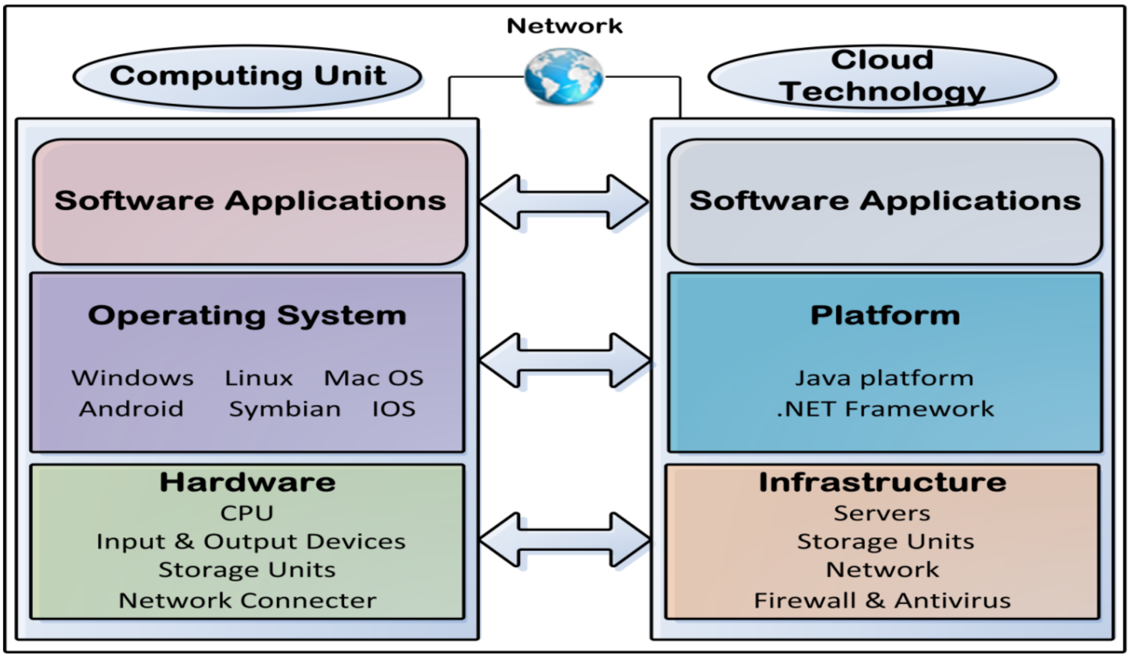


Figure 2-4: Computing device and cloud computing technology relationship (Yadekar et al., 2013)

Cloud computing technology has the same elements as a traditional computer, but with different expressions. Cloud computing technology elements are infrastructure, platform, and software (Misra and Mondal, 2011; Sudha and Viswanatham, 2013). The infrastructure consists of all the necessary services and facilities to provide computing resources for the users. The platform provides a development environment for developers to develop their own application; where a developer user can write, run, upgrade, fix and change their application. The final element provides software applications based on the needs of the user.

2.3 Cloud Manufacturing

The role of technology in the manufacturing industry has become a critical factor and it is fundamental in supporting technical and business processes. Today, the emergence of new technologies such as cloud computing, Internet of Things, virtualisation, and Web services, with the help of existing advanced manufacturing networks, can shift the manufacturing industry from production-oriented manufacturing to services-oriented manufacturing. The combination of innovative technologies and existing manufacturing networks has created a new concept, called “cloud manufacturing.”

Due to the cloud manufacturing is considered as a new emerging concept and live idea which has not settled yet, there are a variety of definitions for cloud manufacturing in the literature; a selection is listed below:

Wu *et al.*, (2013) state that cloud manufacturing is “A customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource loading in response to variable-demand customer generated tasking”.

According to Wang, (2013) cloud manufacturing is “A new-generation service-oriented approach to supporting multiple companies to deploy and manage services for manufacturing operations over the Internet”.

Whereas Xu, (2012) defines cloud manufacturing as “A model for enabling ubiquitous, convenient and on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interactions”.

Gao *et al.*, (2013) write that cloud manufacturing is “A new service-oriented networked manufacturing model, and is an intersectional and mixed product of advanced information technology, manufacturing technology, cloud computing and internet of things”.

Huang *et al.*, (2013) state that cloud manufacturing is “A new service-oriented manufacturing mode that utilizes the internet and service platform to arrange manufacturing resource and provides service according to the customers' demands.”

Laili *et al.*, (2012) propose a definition for cloud manufacturing as follows: “A new networked manufacturing mode which aims at achieving low-cost resource sharing and efficient coordination. It transforms all kinds of manufacturing, simulation, and computing resources and abilities into manufacturing services to form a huge “manufacturing cloud” and distributes them to user the on demand”.

Finally, Tao *et al.*, (2011a) define cloud manufacturing as “A computing and service-oriented manufacturing model developed from existing advanced manufacturing models (e.g., ASP, AM, NM, MGrid) enterprise information technologies under the support of cloud computing, Internet of Things (IoT), virtualization and service-oriented technologies, and advanced computing technologies.”

From the variety definitions, cloud manufacturing can be defined as manufacturing model that provides manufacturing resources and capabilities, and knowledge base platform for collaborations between different users (consumers, manufactures, supplies) to achieve their goals by using the latest Information Technologies and advanced communications networks. Each user in cloud manufacturing has a different purpose, where the consumers need to obtain services or materials for their products. The manufactures offer services and capabilities of production to customers, while the supplies are responsible for providing manufacturing resources and manufacturing capabilities to cloud manufacturing users.

2.3.1 Cloud Manufacturing Frameworks

Cloud manufacturing is a new and emerging area of research within the field of Information Technology. The number of studies discussing cloud manufacturing in the literature is continually rising and gaining the attention of many scholars. This section presents a brief review of the most recent researchs regarding cloud manufacturing.

Guo, (2016) proposed a framework for building a particular cloud manufacturing application system (CMAS). This framework offers a systemic approach to constructing cloud manufacturing from the point of system engineering. The development of the framework was based on analysing six dimensions of cloud manufacturing system. The six dimensions are business model (BM), system structure (SS), production life cycle (PLC), manufacturing state space (MSS), manufacturing industry granularity (MIG), and manufacturing service area (MSA). The framework offered a strategy to analyse cloud manufacturing system composition, function, and characteristics based on the previous six dimensions of cloud manufacturing at the design stage of cloud manufacturing application system. Figure 2-5 demonstrates the the procedure for CMAS design.

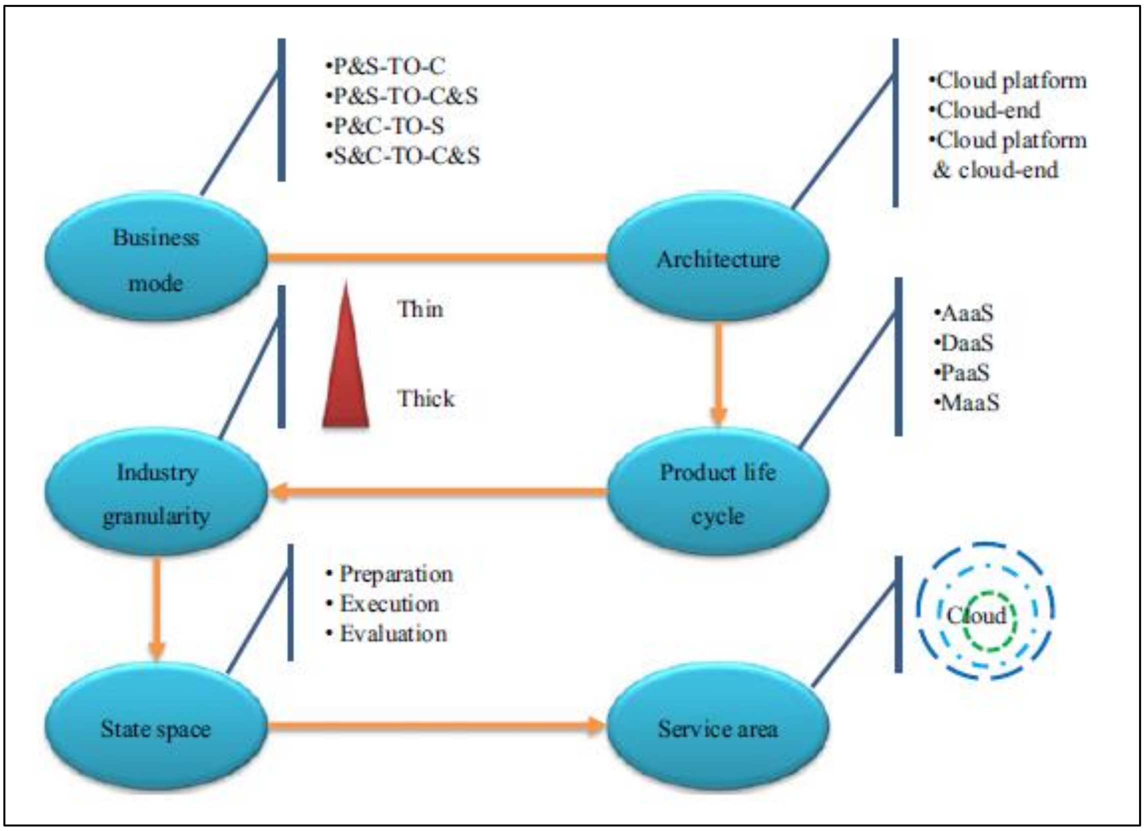


Figure 2-5: General procedure for CMAS design (Guo, 2016)

Wang, (2013) proposed the Internet and Web-based service oriented system for dealing with the dynamic manufacturing processes within a cloud manufacturing environment. This proposed system design is for machine availability monitoring and process planning, which can improve system performance on the shop floor. The system architecture of web-based DPP (distributed process planning) is made up of three modules: Supervisory Planning, Operation

Planning, and an Execution Control module that handles jobs dispatch. A manufactured part that consisted of 14 machined features was used as a case study for Web-DPP prototype implementation. Figure 2-6 shows cloud manufacturing system architecture of Web-DPP.

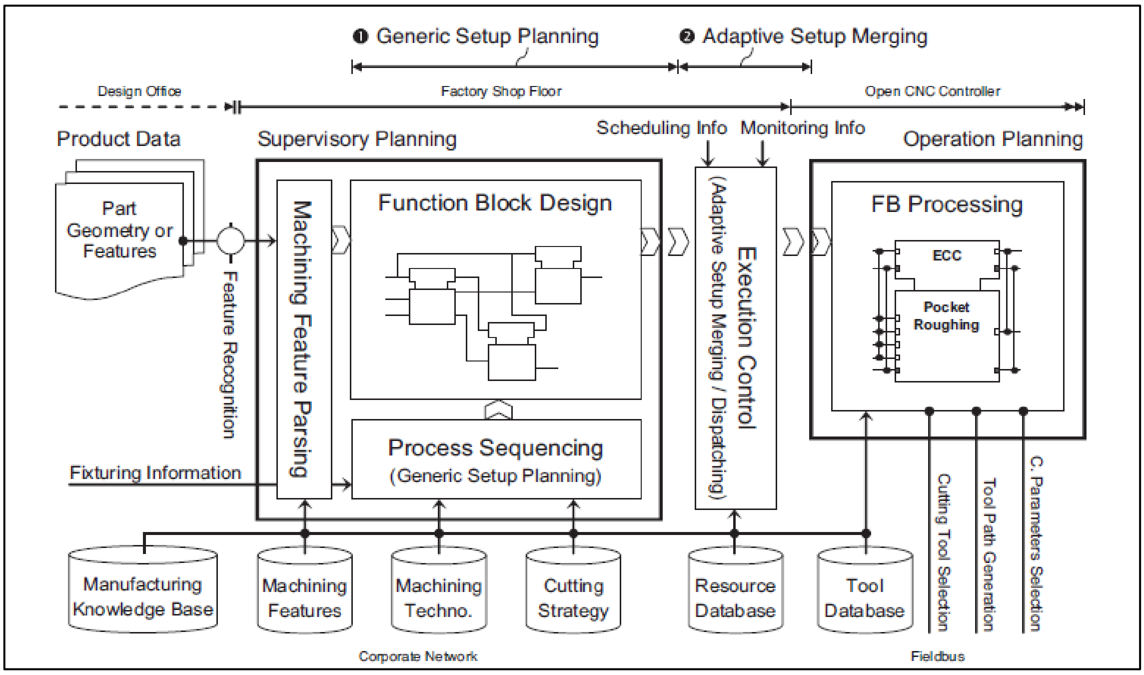


Figure 2-6: System architecture of Web-DPP with combined browser/server functionality (Wang, 2013)

Yan *et al.*, (2013) proposed a framework of a capability services management system for manufacturing equipment. The system consists of three parts: condition perception for manufacturing equipment is responsible for sensing manufacturing equipment resources information; Internet of manufacturing equipment is responsible for gathering information detected by the previous section and transferring it to the management platform; and capability service management platform of manufacturing equipment manages manufacturing equipment capability services into the cloud. Additionally, a detailed implementation plan for the proposed system is presented. Figure 2-7 illustrates the framework of ME-CSMS.

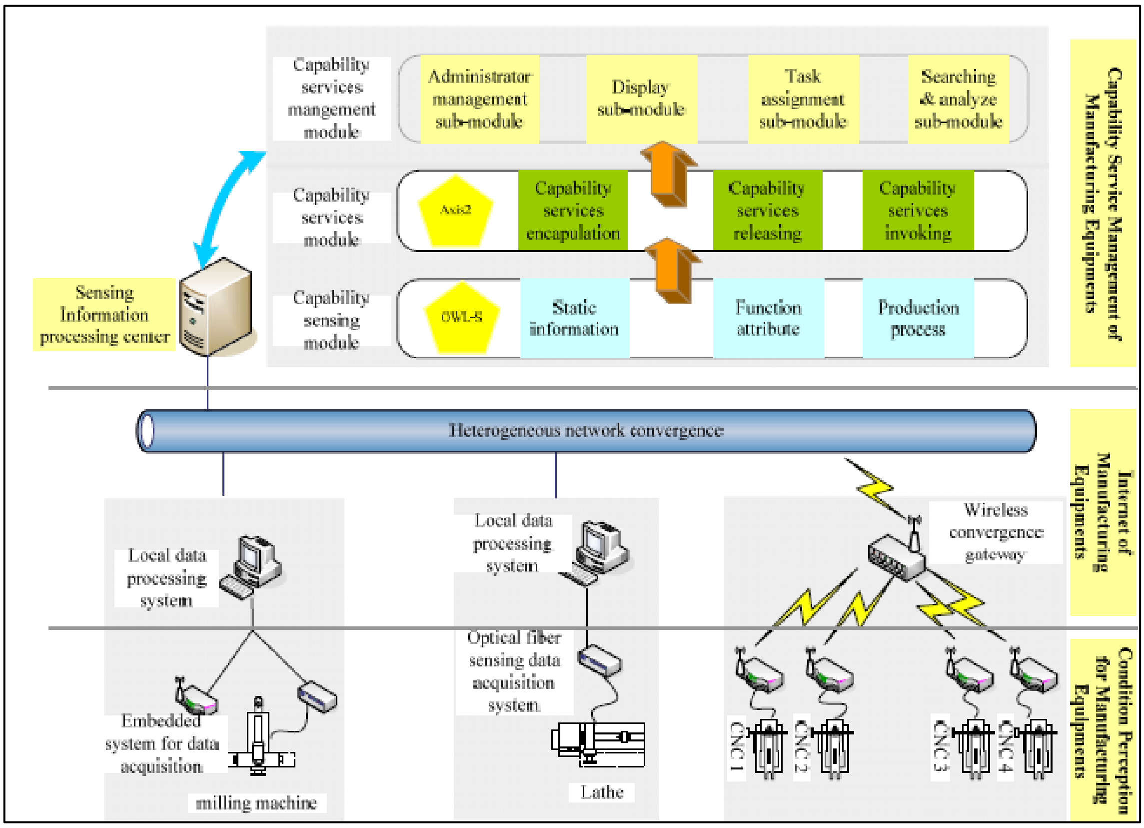


Figure 2-7: Framework of ME-CSMS (Yan *et al.,* 2013)

Xu, (2012) illustrated four layers of a cloud manufacturing system framework: manufacturing resource layer that involves all the manufacturing resources and manufacturing capabilities required in the product development life cycle; manufacturing virtual service layer that involves identification and virtualization of manufacturing resources and the packaging of them as cloud manufacturing services; global service layer that manages these virtualized and encapsulated manufacturing resources and capabilities; and application layer that provides cloud manufacturing services to the users. Figure 2-8 illustrates cloud manufacturing system architecture. While, Wang and Xu (2013) suggest a detailed service-oriented cloud manufacturing system named Interoperable Cloud-based Manufacturing System (ICMS) with three layers design: Smart Cloud Manager (SCM), User Cloud (UCloud), and manufacturing Cloud (MCloud).

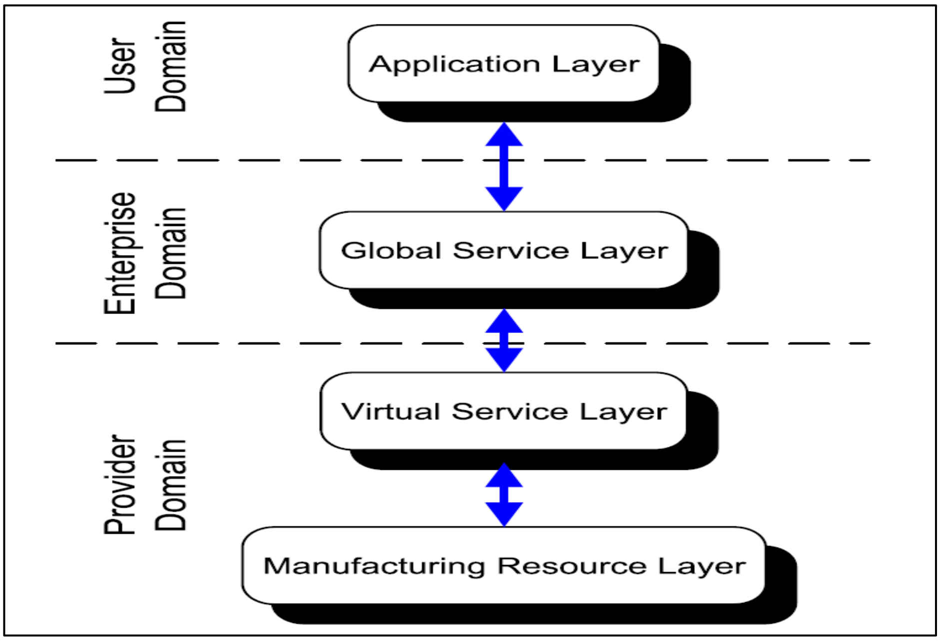


Figure 2-8: Cloud manufacturing system architecture (Xu, 2012)

Lv, (2012) proposed cloud manufacturing architecture consisting of five layers, comprising a physical layer, a virtual layer, a core service layer and a service application layer. The physical resource layer includes all the manufacturing resources and manufacturing capabilities and then links these resources and capabilities to the global network by using technologies such as the Internet of Things (RFID, wired & wireless network, embedded system). In the virtual resource layer, the preparation of manufacturing resources and manufacturing capabilities occurs for the cloud environment by virtually encapsulating physical resources, and publishing them into the core service layer.

The core service layer manages the cloud services of the encapsulation of manufacturing resources and manufacturing capabilities for the users (provider, operator, and consumer). Cloud services include registration, service booking, charge, and search. The application interface layer provides integration between the existing manufacturing application system and the cloud service to deliver a manufacturing application system according to user demands. The final layer, the application layer, provides access for users to request a cloud manufacturing service from any device (PC, laptop, smart phone), from anywhere (company, home or aboard). Figure 2-9 shows the proposed cloud manufacturing architecture.

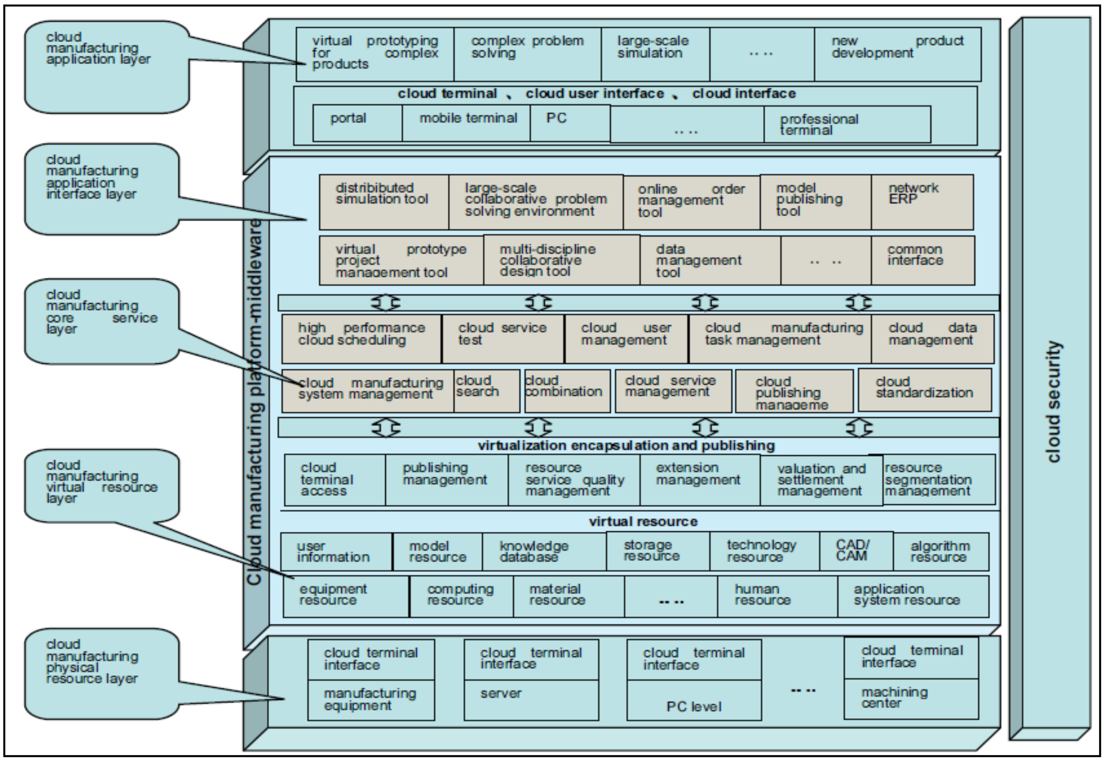


Figure 2-9: Cloud manufacturing architecture (Lv, 2012)

2.3.2 Cloud Manufacturing Characteristics

- **On-demand:**

To provide manufacturing resources and manufacturing capabilities as a service according to user requirements. This allows enterprises to dispense with resources or capabilities that are not needed, or to rearrange any service obtained from the cloud.

- **Dynamic Environment:**

The ability to reshape manufacturing resources according to customers' requirements can reduce time to finish production, produce high quality customised products, and respond to market demands.

- **Economic Solution:**

Using manufacturing resources and manufacturing capabilities as a service can reduce investment costs in IT, by paying only for a service according to the user's needs, as well as improve productivity due to the availability of resources.

- **Knowledge Distribution:**

Provide data and information required in the manufacturing process to the users. Sharing knowledge among manufacturing units, suppliers, customers and partners can enhance the ability to compete with other competitors and improve innovative capability.

- **Resources and Capabilities Accessibility**:

Gather manufacturing resources and manufacturing capabilities from different enterprises that are geographically dispersed into a centralised network over the Internet. In addition, provide access to shared resources from any device, anywhere and anytime.

2.3.3 Cloud Manufacturing Adoption

Many enterprises, which have implemented or are trying to use cloud technology, have significant concerns about this technology. Today, most of the enterprises that use cloud technology have worries about putting their critical data and applications in the cloud because of trust issues (Chow *et al.*, 2009). Khajeh-Hosseini *et al.*, (2010) state that the hosting of all data and applications in the cloud environment will be impossible for any enterprise. They assume there will be a combination of cloud technology and existing servers within the enterprise.

According to Ogunde and Mahnen, (2013), there are some factors that influence the adoption of cloud technology in enterprises:

- **Cost:**

The motivation for enterprises to adopt cloud technology is to reduce the cost of investment in IT. Cloud technology allows enterprises, especially SMEs, to use computing resources and capabilities at low cost. Research indicates that the implementation of cloud technology in an enterprise over five years has financial benefits that cost 37% less than traditional systems.

On the other hand, the implementation of cloud technology can be costly for large enterprises. Using cloud technology can save money on IT infrastructure and applications but may cost more money in bandwidth requirements, especially for large projects for large enterprises.

- **Security:**

Privacy, data deliver, data control and hackers are the major issues of security in the cloud environment, and many enterprises do not want to adopt this technology because of these matters.

However, others believe that cloud technology is an advantage for the enterprise because of the capability of the cloud environment to manage and provide resources (such as the centralisation of data storage and monitoring of data access), and to handle and secure data and applications in the cloud.

- **Availability:**

An important factor influencing the adoption of cloud technology is the availability of cloud services. Network outage and system failures are two reasons for concern for enterprises using cloud technology. Sometimes the disruption may be permanent as a provider company goes out of business, or temporary when there is a failure in the vendor company systems.

Although availability is not a common problem in a cloud environment, several steps can help prevent this issue, such as a Service Level Agreement between enterprises and provider companies, and backup of the enterprise data.

- **User awareness:**

The need to understand and be aware of cloud technology is a key factor for successful adoption of cloud technology. When an enterprise adopts a new technology, acceptance or rejection depends on upon employee awareness of the benefits of the new technology.

- **Perceived ease of use and perceived usefulness:**

Another factor can assist in adopting cloud technology is the perceived ease of use and perceived usefulness. When the users in an enterprise realise how easy it is to use the cloud technology and that this technology will enhance performance in the enterprise, the adoption will become more acceptable.

- **Compliance:**

Lacking control of data location in the cloud may create conflict with regulations and data privacy laws in an enterprise's country, which has an enormous impact on the adoption of cloud technology. An example of this dilemma is that the European Union and American countries have laws prohibiting the moving of certain data types outside the enterprise's country.

- **Vendor lock-in:**

The difficulty of switching between cloud providers is another factor considered by enterprises when adopting cloud technology. Extracting the data that exists in the cloud may be both challenging and costly for the enterprise.

2.3.4 Cloud Manufacturing Challenges

Understating the challenges in cloud manufacturing can be a significant factor for successful implementation of cloud manufacturing into an enterprise. A number of studies reveal the key challenges in cloud manufacturing, as illustrate in Figure 2-10 (Wyld, 2009; Marston *et al.*, 2011; Shade O *et al.*, 2011; Ogunde and Mahnen, 2013).

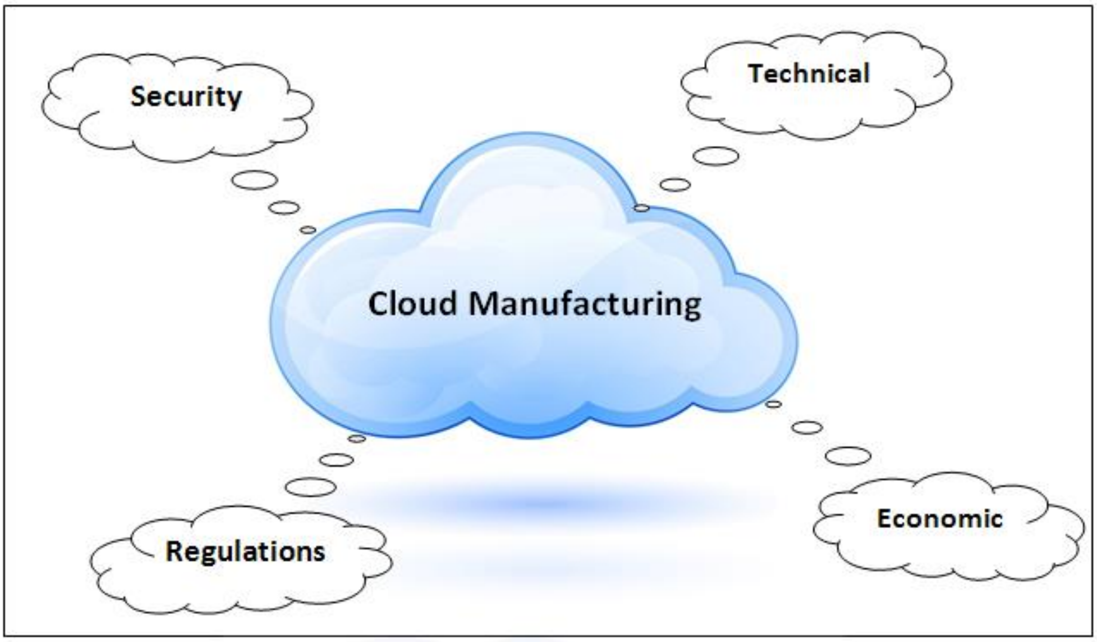


Figure 2-10: Cloud manufacturing challenges (Yadekar *et al.,* 2013)

The most significant challenge in cloud manufacturing is security. Issues including privacy, data deliver, data control and hackers are the primary concerns regarding security in the cloud environment and many enterprises do not want to adopt this technology because of these issues. A survey conducted in 2010 for Novell Company (Harris Interactive, 2010) showed that 91 percent of enterprises were concerned about security problems in the public cloud and 76 percent believed that data is more secure in internal IT departments, in an enterprise's own premises. Also, the complexity of cloud manufacturing can create a fertile environment for security breaches with the losing of control of data and applications that are critical to the enterprise.

Due to the complexly of cloud manufacturing systems that involve the need for numerous advanced technologies and networks to be integrated efficiently, many technical challenges exist in the cloud. Among these challenges are: transferring manufacturing resources and capabilities into cloud; network outage and system failures (availability); the ability to work together with different information systems; more than one cloud, and different software applications (interoperability); and the potential to easily grow the information system due to an increase in demand for cloud services (scalability).

Both manufacturing resources and manufacturing capabilities are core components of a cloud manufacturing system and many technologies (such as Internet of Things and wireless sensors) are needed to coordinate the cloud manufacturing system and manufacturing process. But the amount of data collected from different equipment and tools can lead to overloading in the network, making data exchange very slow in the manufacturing cloud system. Also, more storage space could be needed in the cloud due to data collection of real-time manufacturing resources, requiring more process resources from the cloud to handle this data. All those issues can result in cloud manufacturing system failure.

Although cloud providers invest a lot in their systems to guarantee the availability of the cloud systems, there can be incidents, such as the Gmail outage for 100 minutes in 2009. This can create doubts about cloud capabilities for delivering critical data and applications for enterprises. The cloud providers guarantee to provide cloud services to customers under any circumstances, but sometimes enterprises cannot access their data and cloud resources due to network outage and system failures. The outage may be permanent, as a provider company has gone out of business, or temporary, as a result of a failure in the vendor company's systems. Either way, inability to provide data and cloud resources can be a disaster for the enterprise, which cannot function without its data and cloud resources.

The aim of cloud manufacturing is to share manufacturing resources and capabilities between different parties (manufacturing units, suppliers, other enterprises and customers). However, managing different information systems and different manufacturing systems under a cloud manufacturing umbrella can be a challenging task for both enterprises and cloud providers. For example, legacy systems are substantial and irreplaceable in many enterprises and it is costly and time consuming to put them into the cloud. Moreover, many cloud systems' architectures are designed as closed, which prohibits interaction with other cloud systems. Also, different cloud providers can create a vendor lock-in situation, where each cloud provider has its own way of running the cloud, which is different to other vendors. This limits the choices for enterprises when choosing between other cloud vendors in the market.

Availability, performance, and quality are the primary concerns when enterprises use cloud services. The relationship between cloud providers and their customers' needs to be more efficient and effective by using standards, agreements and regulations to make clear the responsibilities and duties of each party in a cloud manufacturing system. Lacking control of data and its location in the cloud may create conflict with regulations and laws in an enterprise's country. An example of this being the European Union and American countries that have laws which prohibit moving certain types of data outside the enterprise's country.

The cloud providers need to reassure their customers about their services by using Service Level Agreements (SLA). Until now, there is no official standard for cloud computing technology, but there is ongoing work from the International Organisation for Standardisation (ISO), for standardisation in this area. The standard is expected to be a guideline or code of practice for cloud computing technology.

From an economic perspective, the purpose of using cloud manufacturing is to reduce the cost of investment in IT. Cloud technology allows enterprises, especially SMEs, to use computing resources and capabilities at low cost. Research indicates that the implementation of cloud technology in an enterprise over five years has financial benefits that cost 37% less than traditional systems. However, the implementation of cloud manufacturing can raise the cost of using network communication (bandwidth) to send and receive data from the cloud. Moreover, Using cloud manufacturing for large enterprises can be costly due to the need of more cloud resources for their large projects. Also, it is potentially expensive to switch cloud providers because of dissatisfaction with their services, and also time consuming for the enterprise due to the difficulty of extracting existing data in the cloud.

2.3.5 Current Implementation of Cloud Manufacturing

Globalisation, advanced communication networks and new technologies have allowed a small number of newly established companies to implement some form of cloud manufacturing system in their business.

3D Creation Lab and Shapeways are examples of those enterprises that use a cloud manufacturing system to provide 3D printing services online (3D Creation Lab, 2013; Shapeways, 2013). The idea is to allow individuals to become members in their platform, where they can share ideas, create customised products and gain access to 3D printing technology. The first step in the process is to design the product by using any software design tool. Next, the design file is uploaded to company's platform. Then, the system calculates the total cost of this product and the member orders and pays for the service. Next, the printing facility begins to prepare and print the product. Finally, the product ships to the member.

PhotoBox is specialised in digital photo services. Their online services include photo printing, creating Photo books, cards, printed t-shirts, wall decor, photo mugs, personalised mobile phone cases and more (PhotoBox, 2013). First, the customer needs to upload their photos into PhotoBox's platform and select what type service that required. Next, the platform allows the customer to be part of the design process by choosing type, shape and colour of the product. Finally, the customer pays and then receives the product through the mail.

CreateSpace is an on-demand publishing Company, part of the Amazon group of companies. Their services include the publishing of books, music, and video through Internet retail outlets, a private website, bookstores, retailers, libraries, and academic institutions (CreateSpace, 2013). After joining their platform, a member can access their dashboard and choose tools to build and publish their book in a different format (book, EBook, audio book). The platform provides a range of steps that include preparation of the writing material, setup of the book (cover design, page color, ISBN number), proofing and book distribution. After finishing all steps, CreateSpace publishes the book and make it available in one or more book stores.

MFG.com is a marketplace for both buyers who are looking for resources or capability for their product and suppliers that provide material or services (MFG.com, 2013). The idea of MFG.com is to provide a platform to link enterprises to manufacturing resources and capabilities. Uploading CAD files, looking for the right supplier, sending a quote, rating supply service and tracking order delivery are activities conducted by the MFG.com platform. 3Sourceful is another online marketplace that provides a platform to connect enterprises to a network of manufacturing resources and capabilities (3Sourceful, 2013).

Quirky, a small in-house manufacturing company, is another example of cloud manufacturing (Quirky, 2013). The process is as follows: an individual submits an idea to Quirky; Quirky presents this idea to a group of industry experts, friends and community members to decide whether to manufacture this idea or not; if Quirky agrees to manufacture this idea, the individual and community members become part of design process with them; finally, Quirky manufacture this idea and sell it through their website and other retailers.

Implementing some form of cloud manufacturing system has allowed these companies to: reduce time to manufacture a product or to receive a service; produce new inventions; minimise the cost of production and service; and create collaboration. There is a need for complete cloud manufacturing implementation in order for the enterprises to receive full benefits, but cloud manufacturing is a new concept in manufacturing and needs time to become accepted among enterprises.

2.3.6 Current Cloud Manufacturing Projects

With increase interest of transform existing manufacturing systems to new advanced and sophisticated systems such as cloud manufacturing, there are many projects under development on cloud manufacturing worldwide. However, not all cloud manufacturers projects are the same, but the final outcome is to utilise cloud technology solution within the manufacturing industry.

2.3.6.1 CAPP-4-SMEs:

This project aims to enhance the competitiveness of European companies, particularly SMEs, in sustainable manufacturing environment. It adopts Cloud and service-oriented computing approaches, as a service platform to support SMEs to move away from developing and maintaining resource-intensive and standalone CAPP systems and migrate to portable CAPP services accessible and configurable over the Internet. The CAPP-4-SMEs Consortium is comprised of 11 partners (4 universities, 1 multi-national manufacturing company and 6 SMEs) from 5 European countries (Sweden, UK, Greece, Germany and Spain). This project funded by the EU (CAPP-4-SMEs, 2013).

2.3.6.2 ManuCloud:

The objective of the ManuCloud project is the development of a service-oriented IT environment as basis for the next level of manufacturing networks by enabling production-related inter-enterprise integration down to shop floor level. Industrial relevance is guaranteed by involving industrial partners from the photovoltaic, organic lightning and automotive supply industries. The project incorporates experts from various domains and areas of application: Manufacturing domain knowledge from different industries, especially “classical” manufacturing industries (manufacture of parts and assembly), photovoltaic industry (crystalline and organic), and the organic lighting and semiconductor industries. Expertise in different universes of IT-architecture/integration standards, such as OPC, OPC-UA, SEMI EXXX, IEC 61499, STEP and numerous proprietary solutions. Expertise in various implementation technologies from the control level up to the site integration level Major peers of the OLED lighting / organic photovoltaic’s supply chain to support extensive proof-of-concept studies using ManuCloud prototype systems. Exploitation partners that have the capability to bring the ManuCloud results back to industry in the form of commercial products and services. This project is a FP7 project funded by the EU (ManuCloud, 2010).

2.3.6.3 EPSRC Cloud manufacturing:

The research adopts the methods of cloud computing and crowdsourcing. The approach admits new models for open innovation within the manufacturing space, enabling new organisations to arise without the need for a large capital investment. The principle aim is to define and validate the informatics and manufacturing architecture, to support theoretical models, methods and algorithms for cloud manufacturing. The research will benefit the international research community by establishing a long-term research agenda in cloud manufacturing as a multidisciplinary research theme at the interface between computer science, human factors and operations management. The funding organisation is United Kingdom with research team of 14 partners (EPSRC Cloud manufacturing, 2013).

2.3.6.4 CloudSME

The cloudSME project will develop a cloud-based, one-stop-shop solution providing a scalable platform for small or larger scale simulations, and enable the wider take-up of simulation technologies in manufacturing and engineering SMEs. The CloudSME Simulation Platform will support end user SME's to utilise customised simulation applications in the form of Software-as-a-Service (SaaS) based provision. Moreover, simulation software service providers and consulting companies will have access to a Platform-as-a-Service (PaaS) solution that enables them to quickly assemble custom simulation solutions in the cloud for their clients. The cloudSME Simulation Platform will be built on existing and proven technologies provided by the project partners and partially developed in previous European projects. Building on existing technology will enable the project to deliver its results quickly. This project is EU-funded cloudSME project in the Seventh Framework Programme (FP7) collaboration of 29 partners (CloudSME, 2013).

2.3.6.5 Cloud-based Rapid Elastic MAnufacturing (CREMA):

CREMA aims at simplifying the establishment, management, adaptation, and monitoring of dynamic, cross-organisational manufacturing processes following Cloud manufacturing principles. CREMA will develop the means to model, configure, execute, and monitor manufacturing processes, providing end-to-end support for Cloud manufacturing by implementing real systems and testing and demonstrating them in real manufacturing environments. This project is under European Union funding and involves 11 partners (CREMA, 2015).

2.3.6.6 Research on Key Technologies of Cloud Manufacturing Service Platform:

This project proposes to conduct researches for the key technology of cloud manufacturing service platform that by overcoming the share of manufacturing resources and capabilities as well as coordination pattern, standard specification, system structure and core technologies in the internet environment, the cloud manufacturing service platforms for groups and enterprises which manufacture complicated space products and railway transportation equipment is developed as well as the medium-sized and small enterprises manufacturing service platform supporting business coordination and industrial cluster collaboration, to construct corresponding system and start application demonstration for enterprises. The launch of the project will effectively improve the independent innovation capability of domestic complicated space products and railway transportation equipment or other significant products, which provides technical support for internet based national aggregate manufacturing capability and innovation system as well as manufacturing resource and capabilities of on-demand services for Chinese manufacture enterprises to improve their agile manufacturing capacity. The funding body is Ministry of Science and Technology of China with research team of 28 partners (Research on Key Technologies of Cloud Manufacturing Service Platform, 2011).

2.4 Uncertainty

The world is undergoing rapid transformation to becoming a more complex environment as a result of new technologies and advanced communication, innovations and globalisation. These changes lead to new situations that are unknown and unpredictable and they produce doubt though a lack of assurance and confidence. These situations refer to uncertainties and risks that need to be understood and dealt with in the real world. Uncertainties can influence the decision-making process (Erkoyuncu *et al.*, 2013). The ability to understand and manage uncertainty and risk can enhance the decision-making process and allow enterprises to gain competitive advantage.

The term uncertainty has appeared over the past century and been used in a number of different fields of science. In fact, many systems in the world cannot function without uncertainties; such as the stock market, gambling, and weather forecasting. Every enterprise tries to avoid, at any cost, having the undesirable state of ‘uncertainty’ in their system, as more uncertainty in a problem can led to less understanding of that problem (Ross *et al.*, 2013). Implementation of information systems in enterprises may fail due to a number of reasons; some of which are: failure to achieve cost and time targets; not recognising the benefit of the system; and stakeholders being disappointed with system outcomes (Kutsch and Hall, 2005). These reasons exist because the uncertainties and risks in the information system are not understood.

2.4.1 Uncertainty and Risk

In spite of the fact that the term ‘uncertainty’ has existed since the time of the Ancient Greeks, there is still controversy among the scholars about its actual meaning. According to (Samson *et al.*, 2009), the various definitions of uncertainty and risk that exist in literature depend on the problem itself, where every discipline has its own definitions. Although many scholars believe that uncertainty and risk are one concept, some researchers and decision makers like to distinguish between uncertainty and risk. Figure 2-11 shows the different relationships that exist between risk and uncertainty, as described in the literature.

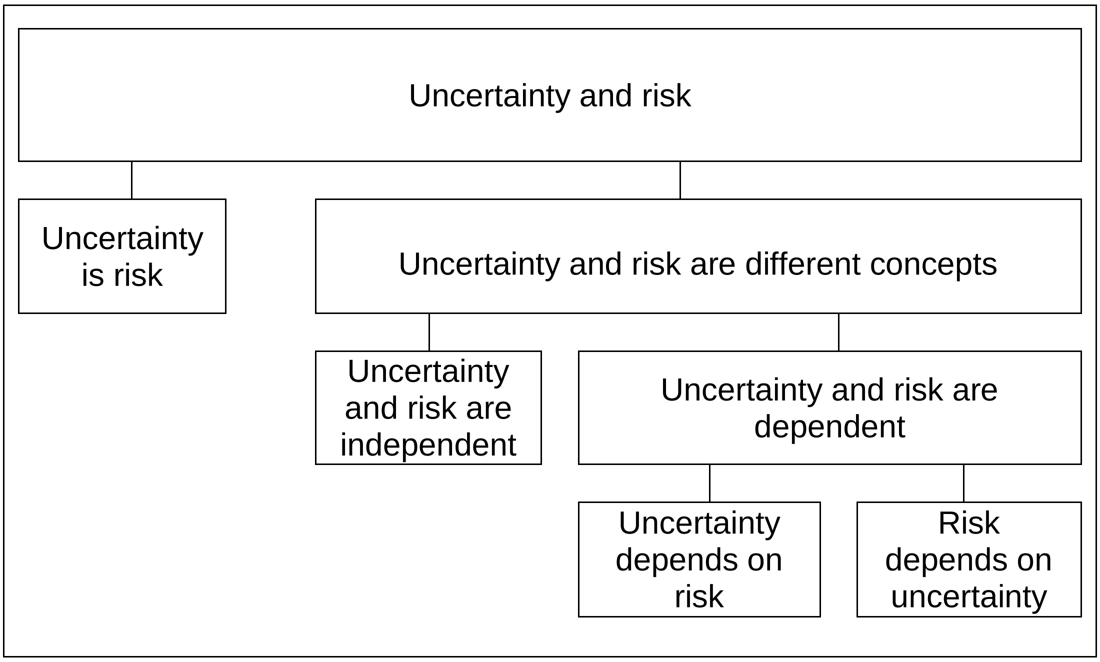


Figure 2-11: Uncertainty and risk relationships (Samson *et al.,* 2009)

A famous distinction between risk and uncertainty has been made by American economist Frank Knight in 1921. Knight, (1921) argues that risk is a form of measurable uncertainty where the probability of each outcome is known, while in uncertainty, the probabilistic outcomes are unknown and cannot be measured due to the unique and completely unknown future conditions of the situation. On other hand, Hubbard, (2014) argues that both uncertainty and risk are measurable. Uncertainty can be measure by assigned a set of probabilities to a set of possibilities for uncertainty, while risk can be measure by a set of possibilities each with quantified probabilities and quantified losses for risk.

The following definitions of uncertainty and risk are considered the most appropriate for this research:
Uncertainty is “the lack of complete certainty, that is, the existence of more than one possibility. The “true” outcome/state/result/value is not known” (Hubbard, 2014). Risk is “a state of uncertainty where some of the possibilities involve a loss, catastrophe, or other undesirable outcome” (Hubbard, 2014). From previous definitions, this research defined uncertainty as an unknown event to us and can be a positive “opportunity” or negative “threat”, and consider risk as part of uncertainty in terms of negative aspects.

2.4.2 Uncertainty and Risk Management

The role of risk management in organisations has become an important factor and is fundamental to support project management in organisations. The ability to influence project threats, identify opportunities and reduce the probability of risk, are all critical elements in a project’s life cycle (Alhawari *et al.*, 2012). Risk management is one of nine knowledge areas in project management and includes the following processes: plan, identify, quality and quantity analysis, responses, and control of risks in the project (Project Management Institute, 2013).

A major criticism of risk management is that it focuses on threats (negative outcomes) and neglects opportunities (positive results) in the project, whereas both threats and opportunities need to managed either together or separately in the decision making process (Ward and Chapman, 2003; Olsson, 2007). Over the years, many organisations have given attention to threats and opportunities in their projects. However, many risk management processes that focus on both threats and opportunities have failed to address uncertainty due to the risk management processes consideration on events and circumstances around the uncertainties and not understood variability and ambiguity in the project (Ward and Chapman, 2003).

Uncertainty management is used to manage threats and opportunities and their implications, explore and understand the origins of uncertainty in the project, and identify all sources of uncertainty. According to (Ward and Chapman, 2003), replacing the term ‘risk’ with ‘uncertainty’ in risk management processes can enhance the identification and managing of uncertainties in the project, since risk is an ambiguous term and considered as a synonym to ‘threat’. Moreover, uncertainty management will focus on sources, different areas, and response options of the uncertainties in the project. This research will use term “uncertainty management” instead of “risk management”.

2.4.3 Uncertainty Nature

To manage the uncertainty, there is a need to understand the nature of uncertainty. The nature of uncertainty can provide description on how the uncertainty has appeared in the system or the surrounding environment (Skinner *et al.*, 2014). The nature of uncertainty can arise from two different sources, lack of knowledge “epistemic uncertainty” and lack of understanding “aleatory uncertainty”.

- **Epistemic uncertainty:**

Epistemic uncertainty comes from gaps in knowledge such as missing data, or ignorance in the system or the surrounding environment (Samson *et al.*, 2009). It can’t be measured or modelled in the physical world (Li *et al.*, 2013). Increase relevant data and research efforts can reduce this type of uncertainty (Walker *et al.*, 2003; Erkoyuncu *et al.*, 2011).

- **Aleatory uncertainty:**

Aleatory uncertainty results in natural variability of the physical environment (Li *et al.*, 2013). This uncertainty will lead to unpredictable outcomes from system or the surrounding environment and cannot be reduced (Erkoyuncu *et al.*, 2011). This type of uncertainty can’t be reduced or eliminated through collecting more data or knowledge (Erkoyuncu *et al.*, 2011; Li *et al.*, 2013).

Figure 2-12 shows the main differences between epistemic and aleatory uncertainties.

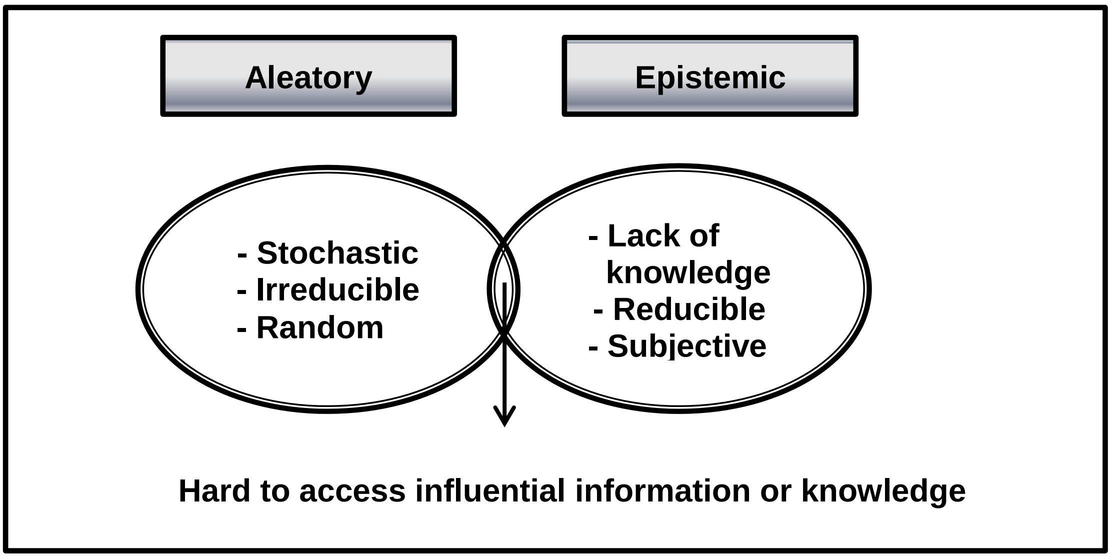


Figure 2-12: Natures of uncertainty (Erkoyuncu *et al.,* 2011)

2.4.4 Uncertainty Levels

The level of uncertainty refers to the degree of knowledge that exists within uncertainty. Understand the knowledge associated with uncertainty can provide applicable methods to tackle and manage uncertainties outputs (Refsgaard *et al.*, 2007). Walker *et al.*, (2003) describe different levels of uncertainty as illustrated in Figure 2-13.

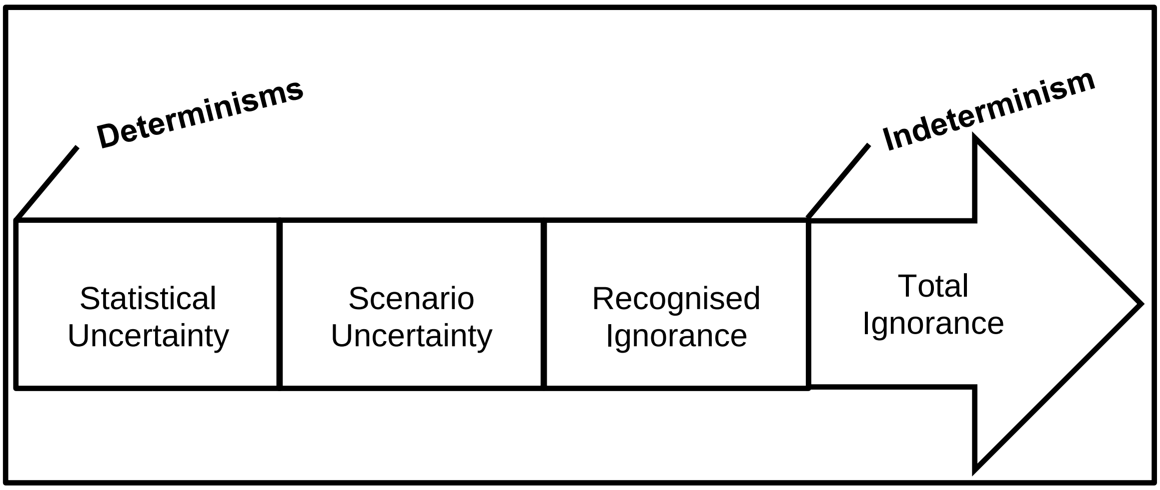


Figure 2-13: Uncertainty levels (Walker *et al.,* 2003)

Determinism can be described as an event with no reoperation of uncertainty, where everything is known for certain (Walker *et al.*, 2003; van Keur *et al.*, 2008). In this situation, the probabilities and outcomes are known to the decision makers (Skinner *et al.*, 2014). Statistical uncertainty can be described as uncertainty with assign probabilities that can provide a statistical measurement for the uncertainty (van Keur *et al.*, 2008; Skinner *et al.*, 2014).

Scenario uncertainty can be described as uncertainty with unknown probabilities and possible known outcomes (van Keur *et al.*, 2008; Skinner *et al.*, 2014). It often used in policy analysis to deliver knowledge about the development of the system certain (Walker *et al.*, 2003; van Keur *et al.*, 2008). Recognised Ignorance can be described as a situation that probabilities or complete set of known outcomes can't be captured (Skinner *et al.*, 2014). The last level of uncertainty is total Ignorance that refers to situation with absolute lack of knowledge, where this type of uncertainty is consider the most important and supreme form of uncertainty because decision makers don't known that is unknown (Walker *et al.*, 2003; van Keur *et al.*, 2008; Skinner *et al.*, 2014).

2.4.5 Uncertainty Management Process

According to (Ward and Chapman, 2003), replacing the term 'risk' with 'uncertainty' in risk management processes can enhance the identification and managing of uncertainties in the project, since risk is an ambiguous term and considered as a synonym to 'threat'. Moreover, uncertainty management will focus on sources, different areas, and response options of the uncertainties in the project. This research will use term "uncertainty management" instead of "risk management".

Uncertainty management processes have evolved and continue to evolve due to the importance of those processes in organisations. A number of researchers and Institutes have presented uncertainty management processes; such as: PMBOK (Project Management Institute, 2013), British Standards Institution, UK Association for Project Management, and (Raftery, 2003). There are four common stages among uncertainty management processes, as shown in Figure 2-14.

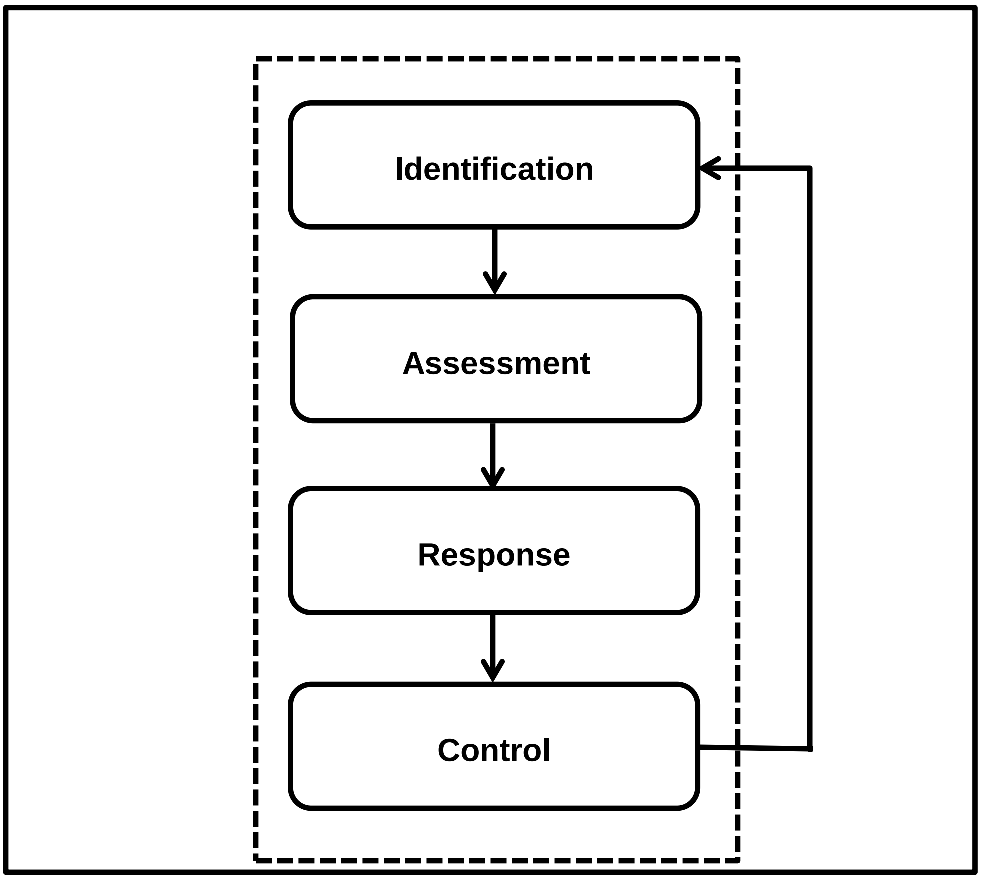


Figure 2-14: Uncertainty management process

- **Identification:**

Identifying the types and sources of uncertainties that exist in the project or system is the first stage in uncertainty management, with documentation of uncertainties in the early stage of the project being an essential step to providing knowledge about the uncertainty.

Uncertainty can be identified by observation, measurement, and recording of poorly understood initial conditions, random effects, uncontrollable effects and unknown effects. There are also other sources of uncertainty, such as incomplete information, lack of knowledge, vagueness, and ambiguity that exist in different models and experiments.

The Delphi technique, survey, brainstorming, documentation reviews (academia, published technical reports), SWOT analysis, diagramming techniques and checklists (Project Management Institute, 2013) are methods and techniques used to identify uncertainties. The result from this process is an uncertainty list, which contains a detailed description of uncertainties of a project.

- **Assessment:**

In this stage, each identified uncertainty is assessed by applying qualitative and quantitative analysis to determine their priority in the project, where the process of prioritising shows the impact and likelihood of an uncertainty. This process allows project members to concentrate on high priority uncertainty.

Qualitative analysis depends on the project team's assessment for each uncertainty to determine their probability and impact in the project; a rating is assigned to each uncertainty based on the probability of uncertainty occurring and its impact in the project. In quantitative analysis a numerical priority rating is assigned to each uncertainty. An uncertainty with a numerical priority rating can provide information on how to deal with uncertainties in the project.

Some methods of quantitative analysis include sensitivity analysis that examines the uncertainty of system output that is associated with input parameter values, to the endpoint of interest (Oughton *et al.*, 2008); Monte-Carlo Simulation relies on repeated random sampling of uncertainties to obtain numerical results, and expected monetary value (EMV) that tests a range of outcome in different scenarios (Raftery, 2003). The outcome from this process is a classification of uncertainties in the project, where each uncertainty can be classified as low, medium or high.

- **Response:**

The purpose of this stage is to develop strategies to deal with uncertainties in the project. This can be very helpful for decision makers to handle both opportunities and threats in the project by reducing threats and enhance opportunities (Raftery, 2003; Project Management Institute, 2013). Avoidance, transference, and mitigation are response strategies to negative uncertainties; whereas, acceptance, exploit, enhance, and share are response strategies to positive uncertainties.

- **Control:**

Uncertainty management is an ongoing process and needs to be controlled during the project duration. The control process is composed of many activities; such as: applying response strategies, monitoring remaining uncertainties, and identifying new uncertainties.

2.4.6 Uncertainty Assessment Methods

This section illustrates various techniques for uncertainty assessment. Uncertainty assessment can allow decision-makers to examine undesirable situations that have an impact on decision-making process by quantify all relevant uncertainties. Uncertainty assessment methods can include Sensitivity Analysis, Monte Carlo simulation, Multiattribute Utility Theroy, Point Estimate, Scenario Analysis, Interval Analysis, Convex Modeling, Fuzzy Set Theory, Data uncertainty engine, Error propagation equations, Expert elicitation, Extended peer review, Multiple model simulation, NUSAP, Quality assurance, and uncertainty matrix (Refsgaard *et al.*, 2007; Durbach and Stewart, 2012; Li *et al.*, 2013; Soroudi and Amraee, 2013).

- ***Monte-Carlo Simulation (MCS)***

Monte-Carlo Simulation is a computational method that produces multiple huge numbers of sceneries of probability distributions for inputs (Hubbard, 2014). In other words, it is a technique that calculates a range of output values for each of uncertain input variables in the system and mapped in scenario simulation. This technique relies on multiple simulations to repeat random sampling to obtain numerical results. Monte-Carlo Simulation is often used for uncertain variables (Goodarzi *et al.*, 2013). The disadvantages of this technique are time consuming, difficulty of analysing massive amount of data outputs (Refsgaard *et al.*, 2007), and require extensive computational capabilities for random values simulations (Goodarzi *et al.*, 2013).

- ***Numeral Unit Spread Assessment Pedigree (NUSAP)***

Funtowicz and Ravetz, (1990) introduce a notational system called Numeral Unit Spread Assessment Pedigree “NUSAP” that goal is to analysis and diagnosis of uncertainty in science for policy, as shown in figure 2-15

(Refsgaard *et al.*, 2007). It can captures uncertainty in both qualitative and quantitative dimensions and allows those dimensions to be interacting in standardised and self-explanatory (van der Sluijs *et al.*, 2005). NUSAP technique combines scientific rigor and uncertainty important on outcome to identify sources of uncertainty (Bouwknegt *et al.*, 2014). The disadvantage of NUSAP is the criteria scoring in the pedigree that is based on subjective judgments can be an enormous range (Refsgaard *et al.*, 2007). On the other hand, NUSAP can be useful to assess parameter uncertainty, systematically reflect assumptions, and problem frames (van der Sluijs *et al.*, 2005).

The methodology of this technique is to use five qualifiers of NUSAP (numeral, unit, spread, assessment, and pedigree) to qualify quantities. Both assessment (expert judgment of reliability) and pedigree (systemic multi-criteria evaluation of different phases of production of a given knowledge base) qualifiers are supplement for quantitative analysis (Numeral/unit/spread) in NUSAP (Kloprogge *et al.*, 2011).

Score	Proxy	Empirical	Method	Validation
4	Exact measure	Large sample direct measurements	Best available practice	Compared with independent measurements of same variable
3	Good fit or measure	Small sample direct measurements	Reliable method commonly accepted	Compared with independent measurements of closely related variable
2	Well correlated	Modelled/derived data	Acceptable method limited consensus on reliability	Compared with measurements not independent
1	Weak correlation	Educated guesses/rule of thumb estimate	Preliminary methods unknown reliability	Weak/indirect validation
0	Not clearly related	Crude speculation	No discernible rigor	No validation

Figure 2-15: Pedigree matrix criteria (Van Der Sluijs *et al.,* 2005)

The pedigree in NUSAP acts as a guide for elicitation process to evaluate the knowledge that is used through a set of pedigree criteria (Funtowicz and Ravetz, 1990). Examples of pedigree criteria are: empirical criterion that indicates to the degree of direct observations, measurements and statistics that are used in estimate the variable, method criterion that indicates to the quality in processing and measuring data, and validation criterion that indicates to the ability level to cross-check the data and assumptions used to produce the number of the parameter contrary to independent sources.

- **Multiple-criteria decision analysis (MCDA)**

Multiple-criteria decision analysis (MCDA) is a member of operations research discipline that has the ability to handling and solving issues involving multiple factors, significant amount of information and knowledge, and different alternative (Jato-Espino *et al.*, 2014). It is a structured framework that provides advanced calculation methods for both qualitative and quantitative decision criteria (Myllyviita *et al.*, 2014), and provides decisions to decision makers in a situation where there are several conflicting criteria (Løken, 2007; Zavadskas *et al.*, 2014).

There are different weighting methods based on elicitation in MCDM approach that uses experts or stakeholders judgment to weight the impact categories and alternatives (Myllyviita *et al.*, 2014). Some of the weighting techniques include Simple Multi-Attribute Rating Technique (SMART) that implements direct entry of relative scores and weights for criteria and alternatives weighting, Swing Technique that applies the lowest level to the highest level range for weighting decision criteria, and Analytic Hierarchy Process (AHP) that employs a ratio scale pairwise comparison for alternatives.

Simple Multi-Attribute Rating Technique (SMART) is proposed by Edwards in 1971 (Edwards, 1971), and becomes a commonly useful tool to decision-makers in the real world (Edwards and Barron, 1994). This technique is a simple tool to implement, its alternatives are independent, eliciting numerical judgment, deals with both qualitative and quantitative criteria, creates a linear form, and straight forward for entering the scores and weight. The downside to this technique is the inability to capture all details and complexities of the real problem (Goodwin and Wright, 2014). SMART technique can conduct in 8 steps:

1. Identify decision maker
2. Identify uncertainties that will be analysis.
3. Identify the relevant dimensions of cloud manufacturing (four dimensions were identified from industry interaction)
4. Rank the dimensions according to their importance to the decision maker.
5. Rate the dimensions by assigning numerical ratio judgments of the relative importance of attributes.
6. Calculate weight for each dimension by sum importance weight and divide by total weight.
7. Calculate weight average of each uncertainty on each dimension by assigning value on 0-10 scale with 0 as worst value and 10 as ideal value.
8. Calculate a score for each uncertainty by multiplying each scaled value of uncertainty into their weighted dimension and then sum all scores for each uncertainty.

Analytic Hierarchy Process (AHP) (Saaty, 1990) is another MCDA method that has been broadly applied in multi criteria decision situations, and it uses pairwise comparisons to analysis the alternatives that exist in the problem (Durbach *et al.*, 2014). AHP methodology begins by structuring the problem and then applies pairwise comparisons for the alternatives to obtain the judgmental matrix. Next, calculate local weights and consistency of comparisons. Finally, local weights of alternatives are aggregated (Subramanian and Ramanathan, 2012).

AHP is straightforward and flexible tool to implement, and it deals with both qualitative and quantitative criteria (Løken, 2007). However, AHP becomes time consumer in a large number of alternatives (Løken, 2007), and it becomes inconsistent because of decision maker expression (Durbach and Stewart, 2012).

- **Sensitivity analysis (SA)**

Sensitivity analysis is "the study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input" (Saltelli, 2008). SA aim is to investigate the response of model outputs to the changes in model inputs (Uusitalo *et al.*, 2015). The benefits of this technique are the ability to provide awareness of the influence of all types of changes in the input, and differentiate the important of parameters for the accuracy of the outcome (Refsgaard *et al.*, 2007). However, SA disadvantages are that it tackles uncertainty in model's values and parameters and neglects model's structure and can be unfeasible due to time limitation and other resources (Uusitalo *et al.*, 2015).

- **Expert Elicitation**

Expert Elicitation is a methodology to elicit, codify, and combine information and knowledge from individuals with expertise in the particular field (Ryan *et al.*, 2012). It has been used in situations that are insufficient empirical data available to quantify uncertainties (Refsgaard *et al.*, 2007). This technique can be conducted in the form of interviews, workshops, repeatable performance feedback, and questionnaires (Leach *et al.*, 2014). The main limitation is subjective judgements by experts (Refsgaard *et al.*, 2007; Uusitalo *et al.*, 2015).

2.4.7 Initial Identification of Uncertainty Factors

To develop a primary list of uncertainty factors, an extensive literature review was conducted to capture the challenges of cloud technology in the manufacturing, and also gathering information from well-known organisations that interested in cloud computing technology and documents available to the public from companies' website were an important source of data collection.

The focus was on literature related to cloud technology implementation in manufacturing and its challenges and technical reports. To identify publications related to cloud technology in manufacturing, a search in both academic database and search engines was conducted and limited to Keywords: cloud computing, cloud manufacturing, cloud technologies, cloud risks, cloud uncertainty, cloud security, and manufacturing.

The selected industrial reports including: “Top Threats to Cloud Computing V1.0” from Cloud Security Alliance (CSA) (Cloud Security Alliance, 2010), “NIST Cloud Computing Standards Roadmap” (Badger *et al.*, 2011) and “Cloud Computing Synopsis and Recommendations” (Badger *et al.*, 2011) from National Institute of Standards and technology, “Cloud Computing: Benefits, risks and recommendations for information security” from European Network and Information Security Agency (ENISA) (Dupré and Haeberlen, 2009), “Unleashing the Potential of Cloud Computing in Europe” from European Commission (Tobergte and Curtis, 2013), “Cloud computing issues and impacts” from Global technology Industry (Ernst and Young, 2011), and “Moving to the Cloud: An Introduction to Cloud Computing in Government” from IBM Centre for the Business of Government (Wyld, 2009).

An initial list of 37 uncertainty factors has been excreted from the results in this chapter and can be viewed in Table 2-1.

No	Factor	No	Factor
1	Availability	20	Data control
2	Scalability	21	Data transition
3	Interoperability among clouds	22	Data Disclosure
4	Interoperability between clouds and in-house infrastructure	23	Employees resistance for transition into cloud
5	Hacking	24	Lack of Transparency
6	Quality of Service (QoS)	25	User awareness
7	Isolation of workloads of multi-tenant	26	Insecure cloud Services interfaces
8	System Integrity	27	Vender-Lock in
9	Network connection	28	Data Location
10	Fault-tolerance	29	Setting Prices
11	Transform manufacturing resources and capabilities into cloud	30	Compliance with different rules that are different from country to country
12	Latency	31	Licensing
13	Cloud provider company Shutdown	32	Raise the cost of using network communication (bandwidth)
14	Migrate workload locations	33	Training existing IT staff
15	Shared Cloud Infrastructures	34	Cloud Resources overload
16	Disaster Recovery	35	Cost of migrate into cloud
17	Stop supporting software application from the vendor	36	User consumption-based billing and metering
18	Compliance with different rules that are different from country to country	37	Lack of Standards for interoperability
19	Network connection between consumers and cloud service		

Table 2-1: Initial uncertainty factor list

2.5 Research Gap Analysis

Cloud manufacturing is regarded as a new area for scientific research, and is related to the existing discipline of Information Technology. This new concept has gained the attention of many scholars in the research community. However, the literature shows that there are huge gaps in cloud manufacturing research. The main research gaps identified include:

1. A lack of understanding of the cloud manufacturing concept. The literature reveals that there is no commonly accepted definition of cloud manufacturing among scholars. Understanding the concept, and identifying its characteristics and attributes can contribute to better and more widespread adoption and implementation of cloud manufacturing.

2. A lack of research directed towards cloud manufacturing implementation. The majority of scholars have concentrated only on cloud manufacturing architecture and its enabling technologies. There is a need to examine cloud manufacturing with real case studies in order to demonstrate the usability and successful implementation of cloud manufacturing in a real-life context.

3. A lack of research work from the managerial point of view in cloud manufacturing. In the literature there are many studies regarding the technical issues around cloud manufacturing. These studies have typically overlooked how to manage cloud manufacturing from a management point of view. Issues that need to be addressed include stakeholders' interactions and their activities, the cloud's standards, and the role of uncertainties.

4. A lack of research regarding how to manage uncertainties in cloud manufacturing. The literature reveals that there is not yet an understanding of uncertainty management for cloud manufacturing. There is a need to identify, assess, and control uncertainties in cloud manufacturing. Therefore, this research proposed a framework to manage uncertainty in cloud manufacturing that offers new insights for

decisions makers on how to deal with uncertainty at the adoption and implementation stages of cloud manufacturing.

2.6 Chapter Summary

In order to understand the context of this research project and identify research gaps, a comprehensive literature review was conducted. In phase one of literature review, the focus was on cloud manufacturing and its types, characteristics, and attributes. The results from this phase led to an understanding of the cloud manufacturing concept, identified cloud manufacturing challenges and characteristics, and illustrated current implementation of cloud manufacturing in real life context.

In phase 2, the focus was on understanding uncertainty and risk and exploring the role of uncertainty in manufacturing and its effects in the cloud environment. The results from this phase were: a differentiation between uncertainty and risk; an understanding of the role of uncertainty (location and level); an illustration of the uncertainty management process; an evaluation of uncertainty assessment methods; and the development of an initial list of uncertainty factors in cloud manufacturing.

3 RESEARCH METHODOLOGY

3.1 Introduction

It is important in scientific research to design a methodology that fulfils the research aim and objectives. This chapter explores different research approaches, types of research purpose, research strategies, and data collection methods. A justification of the research methodology adopted and a detailed description of the research methodology phases are also presented. Figure 3-1 illustrates research methods selection.

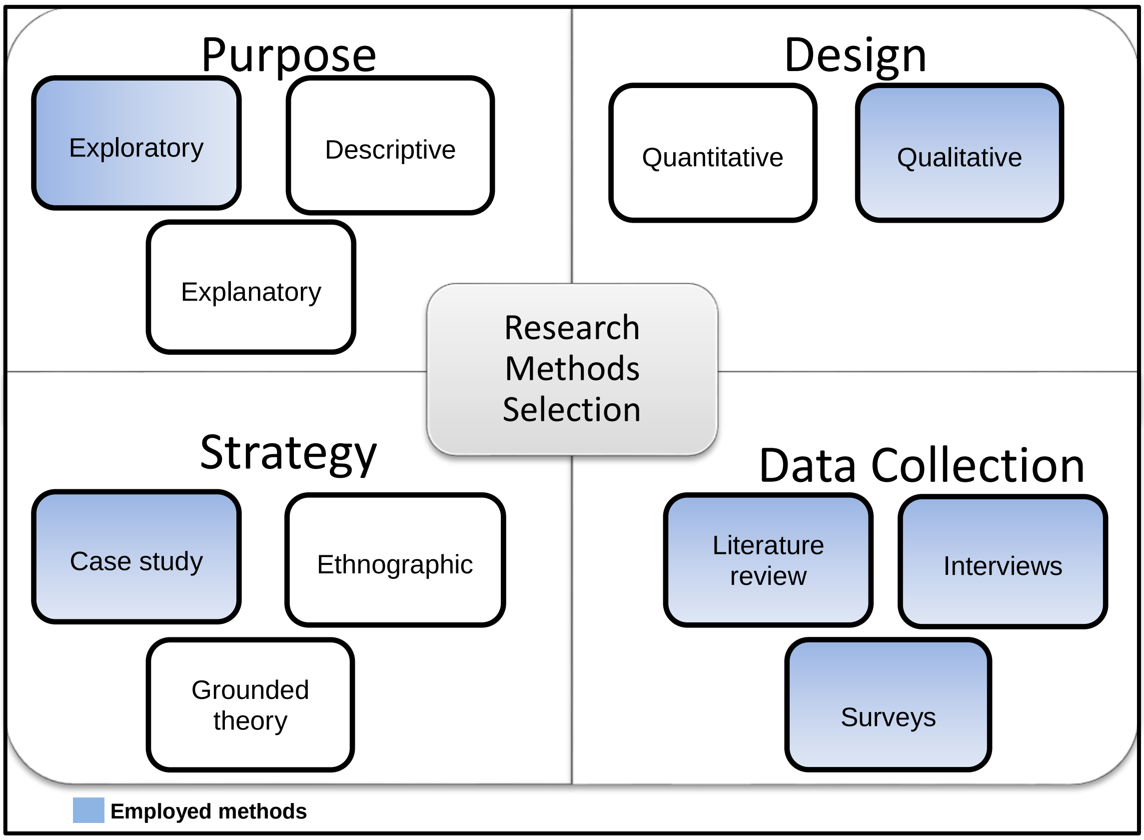


Figure 3-1: Research methods selection

Figure 3-2 shows the chapter structure, whereas sections 2, 3, 4 and 5 address key elements for the formulation of the research methodology, which includes research approach, research purpose, research strategy, and data collection methods. Finally, a detailed methodology of this research is presented in section 3.7, and chapter summary in section 3.8.

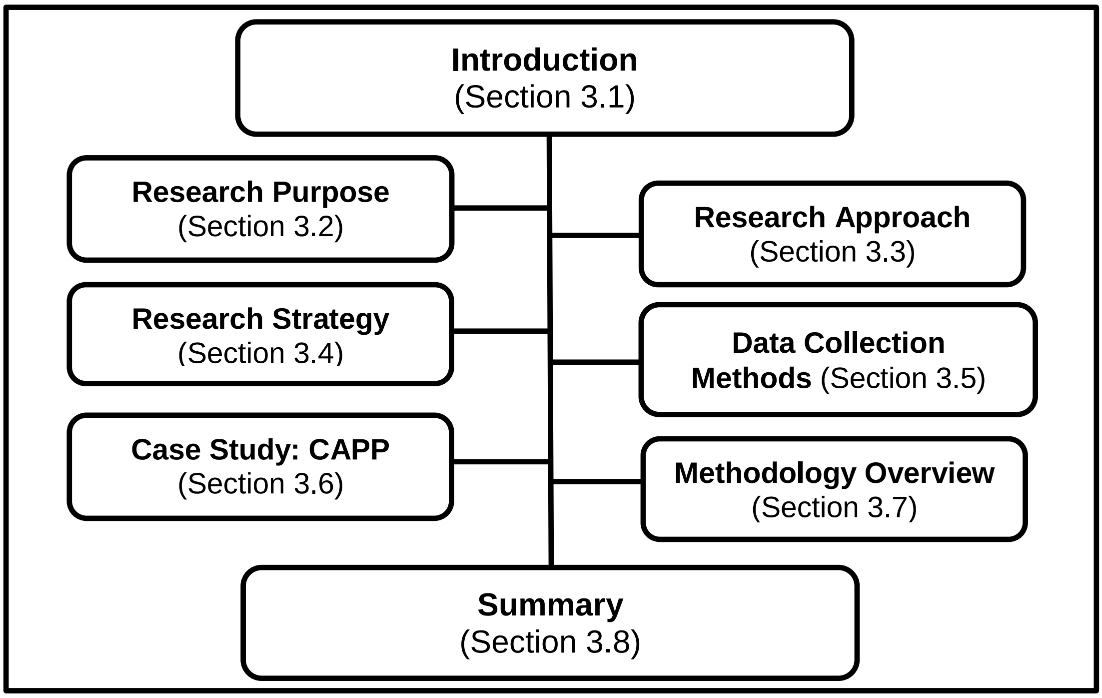


Figure 3-2: Chapter structure

3.2 Research Purpose

There are three main purposes when conducting research: it can be exploratory - discovering, uncovering, exploring; it can be a descriptive - gathering data, describing, summarising; or it can be an explanatory - testing and explaining things (Babbie, 2012). It is also possible for any research to serve more than one purpose (Robson, 2015). The main features of each research purpose are presented in the following sections.

3.2.1 Exploratory

Exploratory research is conducted to explore a new topic that has not been explored or studied previously. This type of research is looking for answers and new insights for the subject of study. In addition, exploratory research is most appropriate for more persistent phenomena. It is used in situations where it is difficult to collect quantitative data.

3.2.2 Descriptive

Descriptive research is conducted to describe situations and events for the subject of study. This research presents an accurate description of the situation through the data and characteristics of the subject of study. It requires extensive knowledge of previous situations. Descriptive research can use both quantitative data and qualitative data as sources for data collection.

3.2.3 Explanatory

Explanatory research is conducted to explain situations or problems for the subject of study. This research attempts to explain patterns and connect ideas of research phenomenon. Moreover, it concentrates on ‘why’ questions, not answering the ‘what, when, where, and how’ questions. This type of research can collect quantitative data and qualitative data.

3.2.4 Research Purpose Selection Justification

This research is based on an exploratory approach because cloud manufacturing is an emerging area that has not been researched in-depth. This approach is suitable for investigating the role of uncertainties in cloud manufacturing and understanding its concept.

3.3 Research Design

The research approach refers to the research plan and procedures that provide a comprehensive description of data collection methods, analysis and interpretation techniques in the research study (Creswell, 2014). There are two main approaches that can be applied in research: quantitative and qualitative. Choosing the right approach depends upon different factors, including the research question, data availability and the researcher’s capabilities (Gilbert, 2008).

3.3.1 Quantitative Research

Creswell (2014) defines quantitative research as “an approach for testing objective theories by examining the relationship between variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analysed using statistical procedures”. In other words, quantitative research uses quantified data (numbers) to explain phenomena by applying numerical analysis (statistical methods) (Aliaga and Gunderson, 2005). This type of research focuses on human behaviour, transfers data into numbers, analyses data through statistical techniques, and results in objectivity between researcher and participants (Robson, 2015).

3.3.2 Qualitative Research

Creswell (2014) defines qualitative research as "an approach to exploring and understanding the meaning individuals or groups ascribe to a social or human problem". In qualitative research, words are the majority source for data collection and this approach does not depend on the numerical form to present the findings. Understanding the phenomena is required at the beginning of qualitative research, but objectivity is not necessary between researcher and participants (Robson, 2015). There are four methods to collecting data in qualitative research: participating in the setting, direct observation, in depth interviews, and documents and material culture analysis (Marshall and Rossman, 2010).

3.3.3 Research Approach Selection Justification

This study employed qualitative research as the purpose of the research is exploratory, and the nature of the research requires investigating new situations. This approach is considered more appropriate for interacting with experts, and more flexible in collecting and analysing data.

3.4 Research Strategies in Qualitative Research

The research strategy is used to answer research questions in an organised method by collecting and analysing data (Saunders *et al.*, 2009). The qualitative research approach is generally associated with three main research strategies: case study, ethnographic study, and grounded theory study (Robson, 2015). The following sub-section describes the three main research strategies.

3.4.1 Types of Research Strategies

Yin (2013) defines case study as "an empirical inquiry that investigates a contemporary phenomenon (the case) in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident". The ethnographic study refers to a "research strategy that focuses on description and interpretation of the culture and social structure of a social group and involves participant observation over an extended period of time" (Robson, 2015). Grounded theory study is defined as "a qualitative strategy of inquiry in which the researcher derives a general, abstract theory of a process, action, or interaction grounded in the views of participants in a study" (Creswell, 2014).

3.4.2 Research Strategy Selection Justification

The case study strategy was applied for this research for a number of reasons. Firstly, this strategy investigates contemporary phenomena, such as the role of uncertainties in cloud manufacturing. Secondly, it an effective approach to address the lack of theoretical background for this research. Finally, the data collected in this strategy provides more in-depth information than other strategies because of interaction with real life situations (case studies).

3.5 Data Collection Methods

Data collection refers to the methods of investigation employed in a systematic and professional manner (Robson, 2015). There are various sources of data in a research project from which the data needs to be gathered by different collection methods. Several data collection methods are presented in the following sub-sections.

3.5.1 Literature Review

According to Gilbert (2008), conducting a literature review leads to insights about the research topic, develops a researcher's capabilities in research and analysis, and transfers a researcher's knowledge obtained from the literature into well-structured written text. In addition, there is recognition of other researchers' efforts, and the uncovering of gaps in prior studies conducted in the same area (Creswell, 2014). The literature review includes a verity of materials such as articles, abstracts, reviews, monographs, dissertations, books, other research reports, and electronic media (Robson, 2015).

3.5.2 Surveys

Surveys are an important and powerful source to collect data about opinions and behaviour from, and about, people (Easterby-Smith *et al.*, 2012; Robson, 2015). Surveys can be self-completion questionnaires (questionnaires), or face-to-face interviews (interviews), telephone interviews (interviews), and internet surveys (e-mail and website) (Robson, 2015). Questions in a survey can be in the form of open-ended questions, closed questions, or both open-ended and closed questions. In open-ended questions, the participant can answer in any way they want; in closed questions, the question has limited possible answers (Gilbert, 2008).

3.5.3 Interviews

Interviews are widely used in qualitative research as a method for collecting data (Gilbert, 2008; Robson, 2015). Interviews involve a series of questions asked by a researcher leading to answers from participants that elicit their thoughts and opinions (Creswell, 2014). This type of data collecting method can be a useful alternative to observation, can provide historical information, and be used by the interviewer to control the interview (Creswell, 2014).

Interviews can be conducted in different forms, such as a one-to-one interview, a focus group interview, a telephone interview, or an e-mail interview (Easterby-Smith *et al.*, 2012; Robson, 2015). Robson (2015) differentiates three types of interviews according to the level of standardisation and structure: fully structured interviews, semi structured interviews, and unstructured interviews.

In fully structured interviews, the questions are predetermined in a pre-set order, and the wording is in the same form in every interview (Gilbert, 2008; Robson, 2015). Questions and answers have a high degree of standardisation (Easterby-Smith *et al.*, 2012). In semi structured interviews, the questions are predetermined with the option to alter the wording and order of the questions (Gilbert, 2008; Robson, 2015). This type of interview is referred to as an “in-depth interview” since it allows for uncovering fresh information, defines new dimensions of the problem, and gains information from an interviewee’s personal experience (Easterby-Smith *et al.*, 2012). In unstructured interviews, the questions are open-ended and the wording and order are very flexible (Gilbert, 2008; Robson, 2015). Questions in semi structured interviews and unstructured interviews provide a high degree of confidentiality because of the interviewee's replies that can more personal in nature (Easterby-Smith *et al.*, 2012).

3.6 Case Study: CAPP

Innovative knowledge-based Computer Aided Process Planning (CAPP) is a key enabler to minimise costs and improve adaptability, responsiveness, robustness, and sustainability of manufacturing processes. This CAPP-4-SMEs project, planned for 36 month duration and 480 person-months, is aimed at enhancing the competitiveness of European companies, particularly SMEs, in a sustainable manufacturing environment. The CAPP-4-SMEs Consortium is comprised of 11 partners (4 universities, 1 multi-national manufacturing company and 6 SMEs) from 5 European countries (Sweden, UK, Greece, Germany and Spain).

The complementary expertise of the academic and industrial European partners in the project enables knowledge sharing, and the dissemination and exploitation of scientific findings, industrial applications and technical know-hows across the EU in an international dimension. Technical innovations will be achieved through collaborative RTD activities oriented towards industrial applications for factories of the future.

3.7 Research Methodology Overview

To achieve the aim and objectives of the research, the researcher adopted exploratory research with a qualitative approach and case study strategy. A detailed methodology that consists of three phases is presented in the next sections. Figure 3-3 shows the adopted methodology for this research.

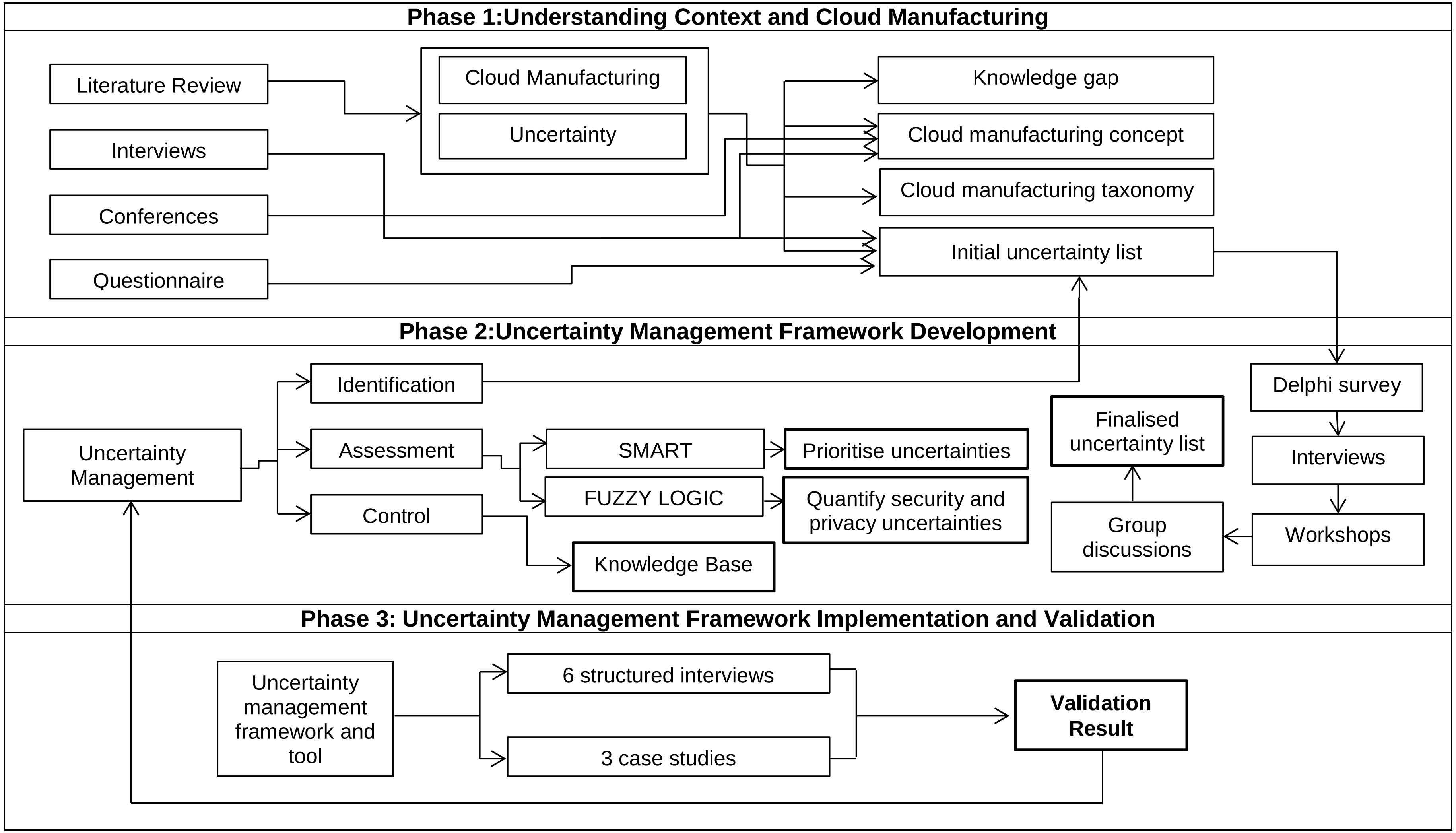


Figure 3-3: Research methodology

3.7.1 Phase 1: Understanding the Context and Cloud Manufacturing

The first step was conducting a comprehensive literature review to understand the research aspects. In this phase, the focus was on cloud manufacturing and its types, characteristics and attributes, and explores the role of uncertainty in manufacturing and its effects in the cloud environment. Additionally, different approaches to managing the uncertainties in cloud manufacturing were identified.

Subsequently, a number of activities have been carried out in order to explore the concept of cloud manufacturing, and determine the challenges and issues within cloud manufacturing. Firstly, unstructured interviews with both industry and academia professionals were conducted to investigate problems and difficulties of cloud manufacturing. Secondly, a questionnaire was distributed to survey the industry regarding cloud technology. Thirdly, conferences were attended in order to gain insights regarding cloud manufacturing and facilitate networking with experts.

During this stage, the researcher reviewed journal papers, conference papers, textbooks, trusted websites articles, newspapers, and industrial reports that cover the cloud environment and uncertainty. Conferences were attended in order to meet with experts and understand the concept of cloud manufacturing. And a survey of industry regarding cloud manufacturing issues was undertaken. The keywords used to search the literature for this research were: cloud technology, cloud manufacturing, cloud computing, uncertainty, and uncertainty Management.

The key result from this phase was identifying the knowledge gap missing from the literature. Also, this phase provided a better understanding of cloud manufacturing by delivering a cloud manufacturing taxonomy, and the knowledge gathered about uncertainties in cloud manufacturing allowed the researcher to determine strategies to approach uncertainties in cloud manufacturing. In addition, an initial uncertainty list was generated.

3.7.2 Phase 2: Uncertainty Management Framework Development

The results from the previous phase served as a foundation to develop a framework to manage uncertainties in cloud manufacturing. This framework provides guidance to deal with uncertainty in cloud manufacturing. The framework includes a cloud manufacturing taxonomy, a process to identify uncertainties, an approach to assess uncertainty, and mitigation strategies to control uncertainty in cloud manufacturing.

There are several steps required to manage the uncertainties. Uncertainty management begins with the uncertainty identification process. The identification process includes three phases. Initially there is an uncertainty factors list preparation phase; this utilises literature, documentation, questionnaires and brainstorming. Secondly comes the uncertainty factors list formulation phase, which refines the list of uncertainty factors through Delphi survey, interviews, and workshops with experts in both industry and academia. Finally, the uncertainty factors list finalisation phase confirms the list of uncertainty factors through interviews and group discussions.

The next step in uncertainty management is assessment process. Assessment process is conducted in two phases. The first phase is application of Simple Multi-Attribute Rating Technique (SMART) to prioritise each identified uncertainty factor. The second phase uses a fuzzy rule-based system (FRBS) to quantify security and privacy uncertainty factors.

The final step in uncertainty management is control process. This step allows for the selection of strategies and solutions to mitigate security and privacy uncertainty factors. The control process constructs a knowledge base for security and privacy uncertainty factors regarding confidentiality, integrity, and availability in cloud manufacturing. The knowledge base provides recommendations and solutions to control and deal with security and privacy uncertainty factors in cloud manufacturing.

3.7.3 Phase 3: Uncertainty Management Framework Implementation and Validation

The final phase included two procedures. Firstly, the framework concepts (taxonomy, list of uncertainties, uncertainty management) were validated during the research period through experts from both industry and academic fields. Secondly, the framework and its tool were verified and validated with three case studies and six experts. The validation process was used to ensure the usefulness of the framework and make any changes if necessary according to validation findings. The case studies were selected from different industries that included manufacturing, government services organisations, and the military. The expert opinions were drawn from a group of six experts in the Information Technology field to verify the framework's tool.

3.8 Chapter Summary

This chapter has examined research approaches, research purpose, research strategies, and data collection methods. Justification of research methods selection was also provided in this chapter. Furthermore, the research methodology was presented in detail to show the development process for the uncertainty management framework in cloud manufacturing for small and medium enterprises (SMEs).

4 UNDERSTANDING CLOUD MANUFACTURING

4.1 Introduction

The aim of chapter is to provide a better understanding of cloud manufacturing by exploring the concept of cloud manufacturing, measuring the awareness, capturing requirements and identifying the challenges about cloud manufacturing, and delivering a Taxonomy for cloud manufacturing that help in identifying characteristics and attributes, capture requirements for cloud manufacturing and its types. The outcomes from this chapter contribute towards the development of uncertainty management framework.

The structure of the chapter as follows: The introduction of this chapter is introduced in section 4.1. Next, cloud manufacturing concept is explained by comparing between traditional manufacturing and cloud manufacturing in section 4.2. Then, questionnaire development and findings were demonstrated in section 4.3. Finally, a taxonomy for cloud manufacturing was delivered in section 4.4. The chapter summary is introduced in section 4.5. Figure 4-1 shows the chapter structure.

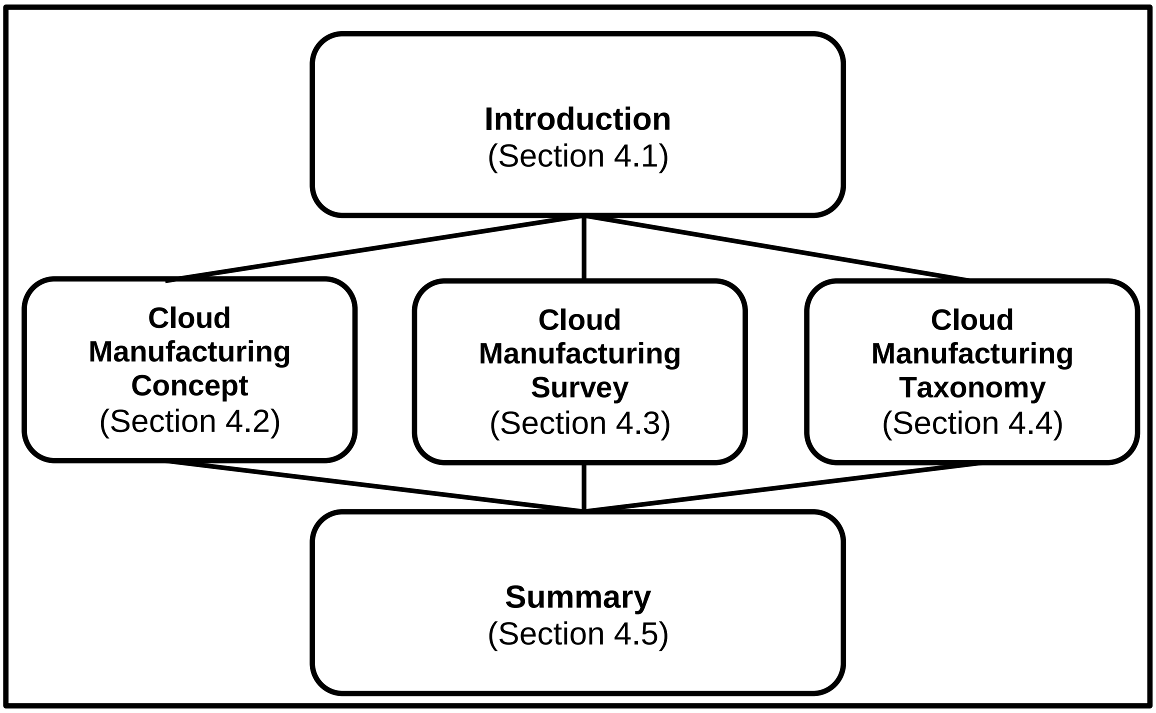


Figure 4-1: Chapter structure

4.2 Cloud Manufacturing Concept

Cloud Manufacturing is a new paradigm which has resulted from changes in global market demands, invention of new technologies, and developments in advanced communication networks. This new paradigm offers faster, safer, more reliable, high-quality, cheap and on-demand services for the whole manufacturing lifecycle. Figure 4-2 illustrates the Cloud Manufacturing concept.

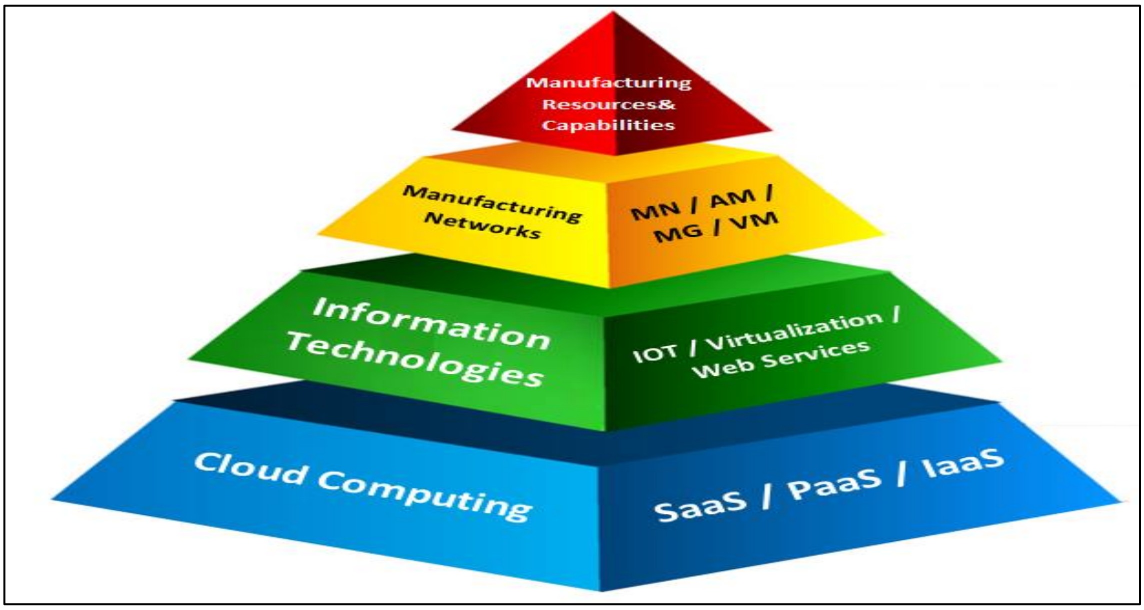


Figure 4-2: Cloud manufacturing concept

The difference between traditional manufacturing and Cloud Manufacturing is illustrated in Figure 4-3. In traditional manufacturing, the process begins with finalisation of the customer's drawings, and selection of appropriate materials. The final drawings are then transferred into a CAD (computer-aided design) system to create detailed engineering designs of the physical part, in the form of two-dimensional or three-dimensional diagrams. A CAM (computer-aided manufacturing) system is employed to use the data from the CAD files to create tool paths that control CNC (Computer Numeric Control) machines. Finally, a particular machine tool receives commands from the CAM system (G-Code) to manufacture the part. This can be done by using either manual or mechanised transformational techniques.

In Cloud Manufacturing, manufacturing resources and manufacturing capabilities that are needed for the whole lifecycle of a product are transformed and encapsulated into a cloud. The process begins when the customer uploads the CAD file of a particular part into the Cloud Manufacturing's platform. Geometrical data obtained from the feature recognition system is then sent to a function block module (a graphical language for programmable logic controllers). The function block module coordinates with other modules (optimisation, visualisation, availability, and database) to provide detailed data for a programmable logic controller (PLC) to manufacture the part. The detailed data includes geometrical data, the appropriate and available CNC machine tool, and the optimal cutting condition. Finally, a particular machine tool receives commands from the PLC to manufacture the part. Thus, by using new technologies, advanced networks, along with intelligent and automatic techniques, this process can be done without any human intervention.

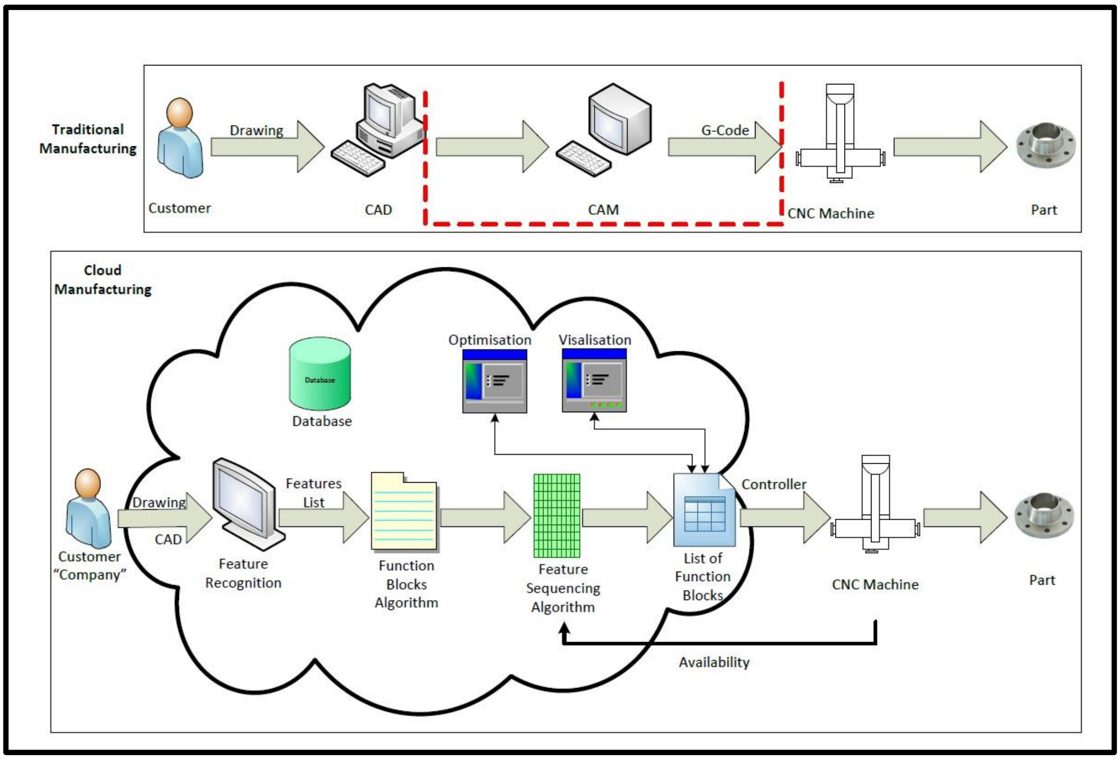


Figure 4-3: Traditional manufacturing and cloud manufacturing (Yadekar *et al.*, 2015)

4.3 Cloud Manufacturing: Industrial Awareness

In order to fulfil the objectives of this research, an online questionnaire was developed and distributed. The aim of this questionnaire was to: capture requirements for those using or considering adopting cloud computing technology in their enterprises; measure the awareness of cloud computing technology among individuals and enterprises; and identify challenges of cloud computing technology in the manufacturing environment.

4.3.1 Questionnaire Design

A pilot questionnaire with a mix of open-ended, closed, and scales questions was designed, based on the literature review, participation in online group discussions (LinkedIn) and published reports. The pilot questionnaire was distributed to a sample of four individuals (two experts and two researchers) to check wording, codes of closed questions, and questionnaire instructions. The feedback from the pilot questionnaire resulted in adding multiple choice answers for some of questions and re-wording other questions. Figure 4-4 shows sample of questionnaire's questions. The final design of the questionnaire includes two sections with a total of 13 questions (See Appendix B.1 for full questionnaire). The first section shows the characteristics of the respondent and their organization. The second section concentrates on the use or adopting of cloud technology in the respondent's organization.

The purpose of using a questionnaire at this stage was to collect data from respondents who are familiar with the cloud technology concept, are already using it, or considering adopting it. The targeted population was LinkedIn groups and JISCMail groups that have similar interests in cloud technology and cloud manufacturing. The author used Cranfield University's Qualtrics survey tool to design the questionnaire instrument. The distribution of the questionnaire was through the email. The email included an invitation to participate in this online survey, an explanation of its aims, a questionnaire link, approximate time to complete the questionnaire, and time frame of the questionnaire (which was one month).

10. What type of data and application were moved/ are considered to be moved into the Cloud?

☐Non- critical data and application
☐Critical data and application
☐Both
☐Other (please specify)

11. Is your organisation using/ considering adopting Cloud technology for:

☐Computational Resources (Infrastructure, platform, software)
☐Manufacturing Resources & Capabilities (equipment, monitor control devices, materials, information systems, software, knowledge, transportations, design, production, simulation, etc)

12. What are the reasons for using/ considering adopting Cloud technology in your organisation? (you can choose more than one answer)

☐Reduce investment cost in IT
☐Ability to access shared resources from any device, anywhere, and anytime.
☐Pricing flexibility (paying only for service according to user's needs)
☐ Collaboration
☐Require new services
☐Scalability (easily grow of information system)
☐Other:

Figure 4-4: Sample of questionnaire's questions

4.3.2 Data Analysis

After closing the survey online, data were collected from Qualtrics's database. According to data, the actual number who completed the questionnaire reached 31 out of 45 respondents from LinkedIn and JISCMail groups. In addition, not every respondent fully answered the entire questions in the questionnaire. Data analysis was executed using Microsoft Excel Version 2010 for simple descriptive statistics (frequencies and percentages), as the sample size (N=31) was small for statistical analysis, with some missing data.

The descriptive data analysis was the method used in analysis the collected data from the questionnaire. This method summarises collected data in a meaningful way and manageable form. The descriptive data analysis use charts, tables, and figures to present the collected data, and use statistic measurements to interpret the collected data. The outcome for using this method is a summarise questionnaire’s data that can easy understand and interpret, and to gain knowledge about cloud manufacturing concept.

4.3.3 Results and Key Finding

Table 4-1 summarises the demographic characteristics of the 31 respondents, showing: organisation size, industry sector, respondent’s occupation, years of experience, and familiarity with the cloud manufacturing concept. The demographic characteristics of respondents were used later in the analysis.

	Respondents
Organization Size	
Micro Enterprise	32%
Small Enterprise	16%
Medium-sized Enterprise	13%
Large Enterprise	39%
Industry Sector	
Manufacturing	6%
Research & Development	10%
Communications	10%
Financial Services	10%
Information Technology	51%
Education	10%
Other	3%
Occupation	
Management	65%
IT Specialist	13%
Researcher	6%
Other	23%
Years of Experience	
1-5 Years	13%
6-10 Years	19%
11-15 Years	10%
16-20 Years	16%
21-25 Years	3%
More than 25 Years	39%
Familiar with cloud manufacturing Concept	
Yes	52%
No	29%
Not sure	19%

Table 4-1: Demographic characteristics of respondents

According to the survey results, SME’s were the dominant category with 61% of total responses, followed by large enterprises, with (39%) response. It can be clearly seen that the majority of respondents belong to the Information Technology sector (about 51%), whereas other industry sectors’ figures are relatively uniform and change from 10% to 3%. 21% of respondents have a management role in their organisation; 12% are IT specialist; 6% working as researchers, and 61% have a different role in their organisation.

The highest percentages of responses in the six groups for ‘years of experience’ belonged to those with more than 25 years; at 39%. The next two groups have lower figures: 6-10 and 16-20 years of experience at 19% and 16% respectively. Percentages reduced for other groups for years of experience, with 13% for the 1-5 group, 10% for group 11-15; and 3% for group 21-25.

Finding (1) Less than half of respondents are not sure or do not know the cloud manufacturing concept.

Respondents were asked to answer questions about their knowledge of the cloud manufacturing concept. 52% of respondents are familiar with the cloud manufacturing concept; 29% of respondents did not know of this concept; 19% are not sure about cloud manufacturing concept, as shown in Figure 4-5.

The finding indicates that the cloud manufacturing concept is still unfamiliar to the industrial and academic professionals. This result due to that the concept is one of the emerging technologies and new manufacturing paradigm that has been surfed a few years ago. Moreover, there is no commonly accepted definition of cloud manufacturing existed in the literature nor in the industries that can clarify this concept. Also, some organisations are using this concept without referring to it as cloud manufacturing.

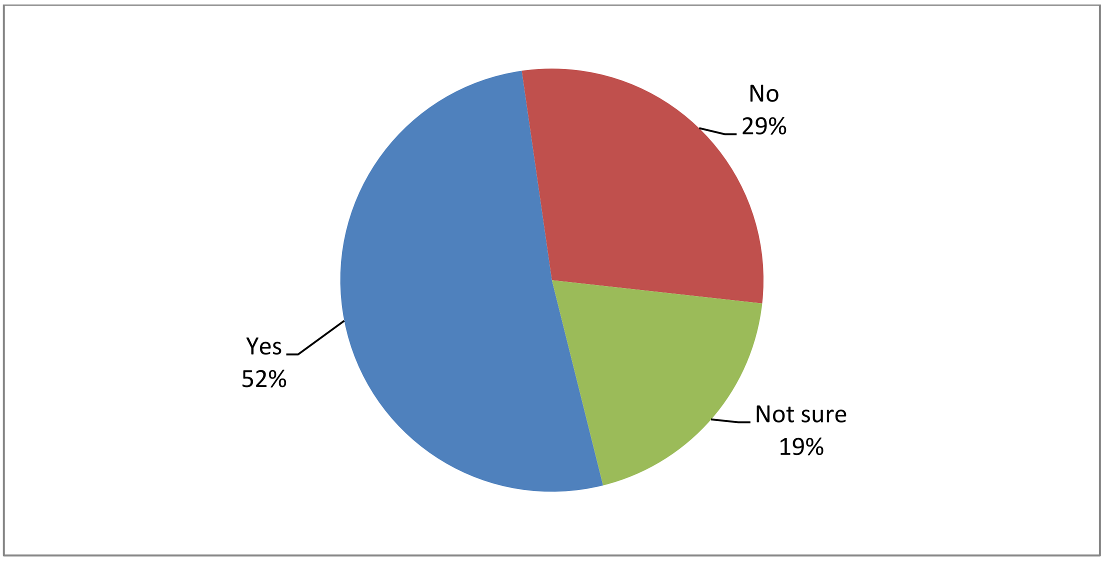


Figure 4-5: Cloud manufacturing concept knowledge

Finding (2) More than half of enterprises are involved only in one aspect of cloud technology.

Figure 4-6 shows the distribution of respondents' answers about their involvement in cloud technology, where involvement in the cloud system was categorised into different groups. The groups can be: cloud operator group that manage and control cloud services; cloud resource provider group that own and provide resources and capabilities for the cloud; cloud user customer group that require access to resources and capabilities; or a researcher group.

The respondents involved in a single aspect of the cloud system had the highest respondent rate (61%), while others involved in more than one aspect had much lower percantages (23% for two aspects and 16% for three aspects).

The finding indicates that the majority of enterprises are only cloud technology to obtain services and products, to provide resources to the cloud, or to operate and manage the cloud. Where in some cases, an enterprise is using the cloud to provide resources and collaborate with other users to obtain services and products. In extreme cases, an enterprise is operating the cloud, providing all or some of resources, and using the cloud to obtain services and products.

This result due to that the enterprises are trying to focus on their core business only rather than focus on IT services issues. Some of enterprises are using cloud technology for a particular purpose only to require resources and capabilities of the cloud (storage, infrastructure,…), and don't want to involve in manage and control cloud services. Whereas some other enterprises' core business are to provide cloud services only, or own resources and capabilities that are used in the cloud.

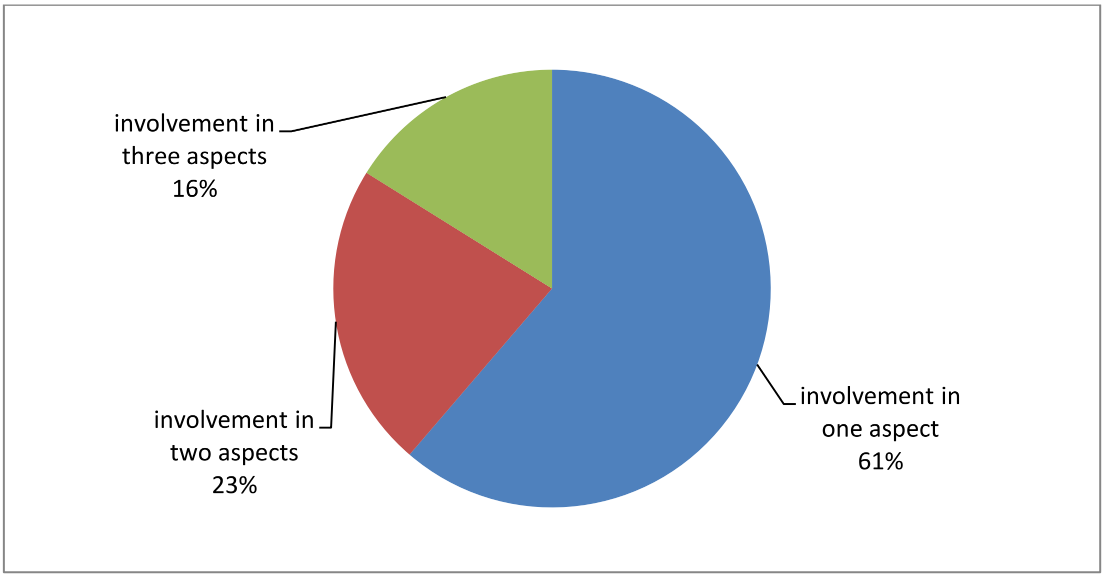


Figure 4-6: Involvement in cloud system

Finding (3) More than half of enterprises are using only one deployment model in their cloud system.

Respondents were asked to identify type of cloud technology deployment model that their organisation is using, where the organisation can use one or more of the deployment models (public, private, hybrid, and community). As illustrated in Figure 4-7, only 61% of respondents are using one deployment model (Hybrid cloud (27%), Community cloud (4%), Public and Private clouds have an equal percentage (15%). The two deployment model category recorded much smaller figures (23%), while three and four deployment model categories have similar values of (8%).

The finding indicates that each type of deployment model has its own characteristics that suit for different situation, and helps organisations to achieve their goals. In addition, many organisations used one or more of the deployment models for different purposes, such as a community cloud to ally with other organisations that have the mutual interests and concerns. Another example is when an organisation used a hybrid cloud for their both critical and non-critical data and application.

Also, among the organisations that using one deployment model, the highest deployment model is a hybrid cloud (27%). This finding indicates that the increasing number of organisation using hybrid cloud comes from organisations' needs to separate their data and resources into the cloud. The Non-critical data and resources are belonging to public cloud, critical data and resources are belonging to private cloud.

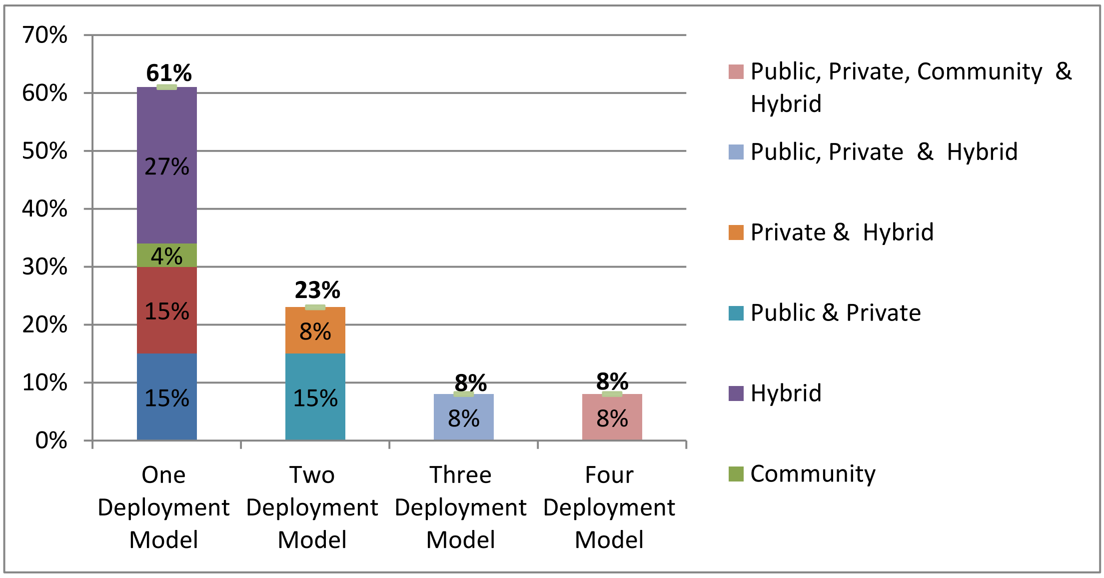


Figure 4-7: Cloud technology deployment model

Finding (4) More than half of enterprises are using cloud technology for both their critical and non- critical data and application.

Figure 4-8 shows the percentage of organisations that moved their critical and non-critical data and applications into the cloud. The majority of organisations moved both critical and non-critical data and application into the cloud (61%), whereas the percentage drops for non-critical data and applications with 31%. Critical data and application is the least popular category with only 8%.

The finding indicates that the majority of enterprises have trust and security issues regarding cloud technology, where the enterprises used different types of clouds for both critical and non-critical data and application. Public cloud, that cost less, for non-critical data and application, and private cloud, that cost more, for critical data and application. The enterprises need to have a control and a secure environment for their critical data and application. Moreover, with more option for cloud deployment models such as hybrid cloud which is a combination of public cloud and private cloud, the enterprises have more flexibility, cost effective, and scalability by using cloud technology.

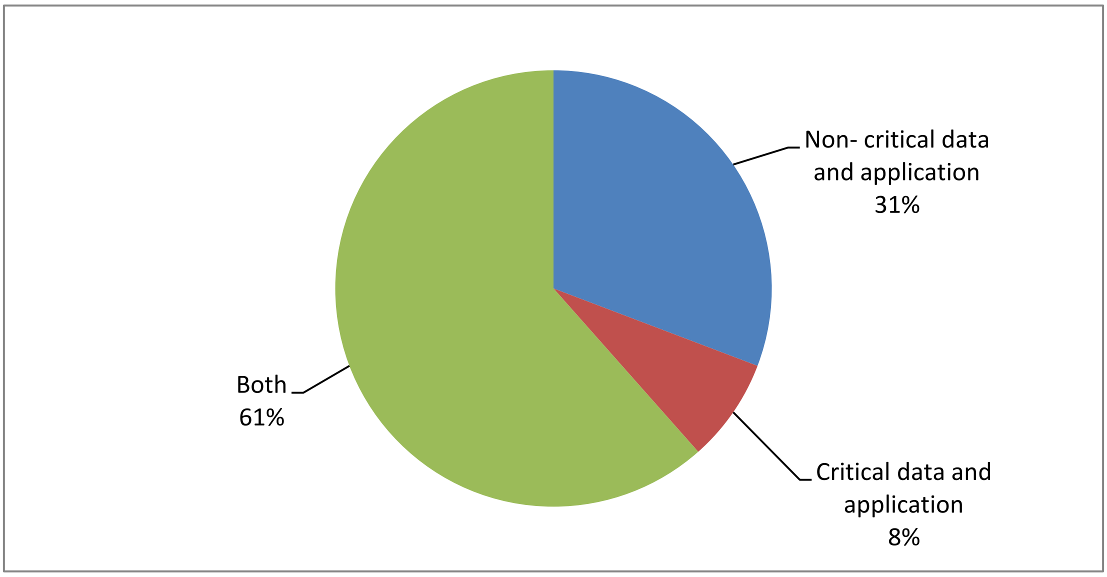


Figure 4-8: Type of data and application

Finding (5) Majority of enterprises are using computational resources as the primary drivers for migrating to the cloud.

Figure 4-9 demonstrates percentages of respondents' organisations using cloud technology to obtain either computational resources or manufacturing resources and capabilities. Figures for the different two resources are wide apart. Organisations that using cloud technology for computational resources have the greatest proportion (88%), while organisations using cloud technology for manufacturing resources and capabilities have the lowest percentage (12%). The finding indicates that the variation is due to:

1. The fast growth of cloud computing market (computational resources) during the past few years.
2. Increased demands on computational resources for SMEs for different reasons.

3. The difficulty of transferring manufacturing resources and capabilities in the cloud.
4. Cloud manufacturing system is still at the early stage of development with only a few companies implementing some form of cloud manufacturing system in their business.

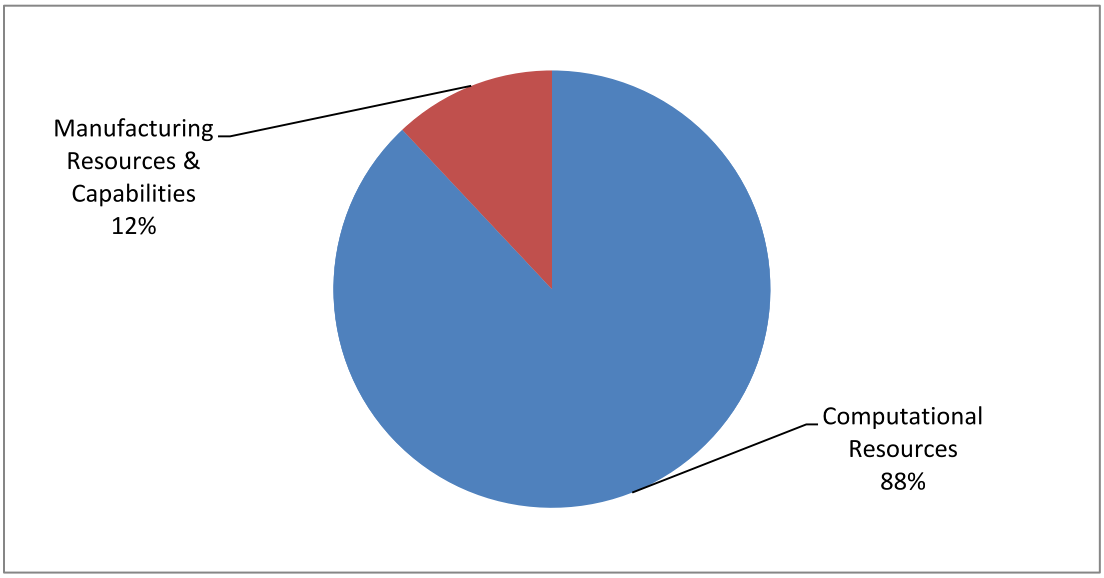


Figure 4-9: Type of cloud technology resources

Finding (6) The majority of enterprises are using, or considering adopting, cloud technology for smooth growth of informatics, due to an increase in demand for cloud services.

From the respondents' perspective, scalability and ability to access shared resource have the highest percentages among reasons to use cloud technology (73% and 69%). The next three reasons have lower rates: starting with reducing investments in IT (58%); and dropping for pricing flexibility (50%), and with a slight decrease for collaboration (49%). Require new services and other reasons have the lowest numbers (19% and 15% respectively) as can be seen in Figure 4-10.

The finding indicates that the enterprises are using cloud technology for more additional resources and flexibility to switch applications at minimum cost because of the rapid growth of advanced technologies and increased competition among enterprises. In addition, scalability in the cloud allows the enterprises to act quickly and easily to upscale or downscale the resources that are needed for their businesses.

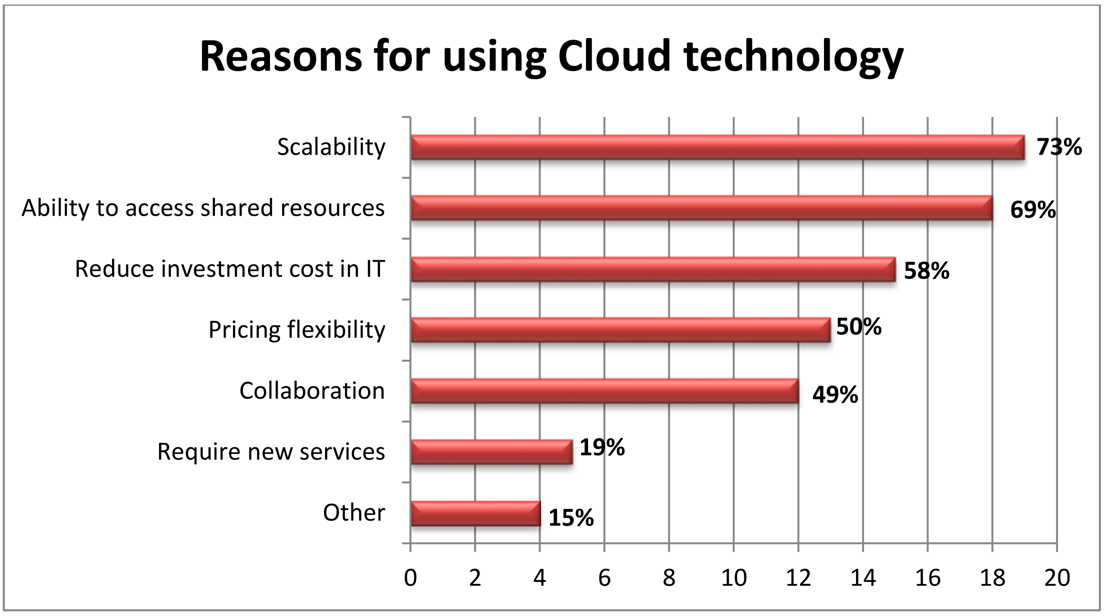


Figure 4-10: Reasons for using cloud technology

Finding (7) Security and privacy and Interoperability challenges are the most important challenges in cloud technology (50% and 69%).

The issues that enterprises have major concerns about include: security (hacking) and privacy (data delivery, data control); in addition to the ability of cloud system to work together with different information systems, more than one cloud, and different software applications.

Table 4-2 shows the statistics of the challenges that influence cloud technology. 50% of respondents believe that 'security & privacy' is the most significant challenge in cloud technology, while 69% consider Interoperability as a critical challenge. Also, respondents selected System Integrity and Scalability as critical challenges (45%, 42% respectively), followed by the Lack of Standards challenge that shares the same percentage in two ranks (very important and quite important with 32%). The challenges, 'Lack of Transparency' and 'Cost to migrate into a cloud' drop in the same rank category, which is quite important (50% and 52% respectively), whereas Quality of Service is a very important challenge with 52%. Finally, respondents divided their answers for Vender-Lock-in into very important and important challenge with (24%).

The finding indicates that the security, privacy, and interoperability issues are highest among challenges that exist in cloud technology. This result due to that the security, privacy, data deliver, data control, and hackers are the major issues of security and privacy in the cloud technology environment, and many enterprises are concern about these matters in the cloud. cloud technology is considering an attractive environment for security breaches and losing control of data and resources that are critical for the enterprises. Also, due to nature of cloud technology which is complex and involves many advanced technologies and networks, the communication between cloud services and enterprises in-house infrastructure can be difficulty and causes problems for both cloud providers and enterprises.

	Most important	Very important	Quite Important	Important	Least important	Mean
Security and Privacy	50%	31%	15%	4%	0	1.73
Interoperability	0	69%	20%	11%	0	2.42
System Integrity	42%	45%	9%	4%	0	1.75
Scalability	31%	42%	19%	4%	4%	2.08
Lack of Standards	0	32%	32%	24%	12%	3.16
Lack of Transparency	17%	13%	50%	12%	8%	2.83
Quality of Service	32%	52%	12%	4%	0	1.88
Vender-Lock in	16%	24%	20%	24%	16%	3.00
Cost to migrate into cloud	16%	8%	52%	16%	8%	2.92

Table 4-2: Challenges of using cloud technology

4.4 Cloud Manufacturing Taxonomy

Taxonomy of cloud manufacturing is presented after conducting a comprehensive review of cloud manufacturing literature. This taxonomy provides a classification of cloud manufacturing into six main areas, where the distinguishing attributes are listed under each main area (Yadekar *et al.*, 2014a, 2016), as shown in Figure 4-11.

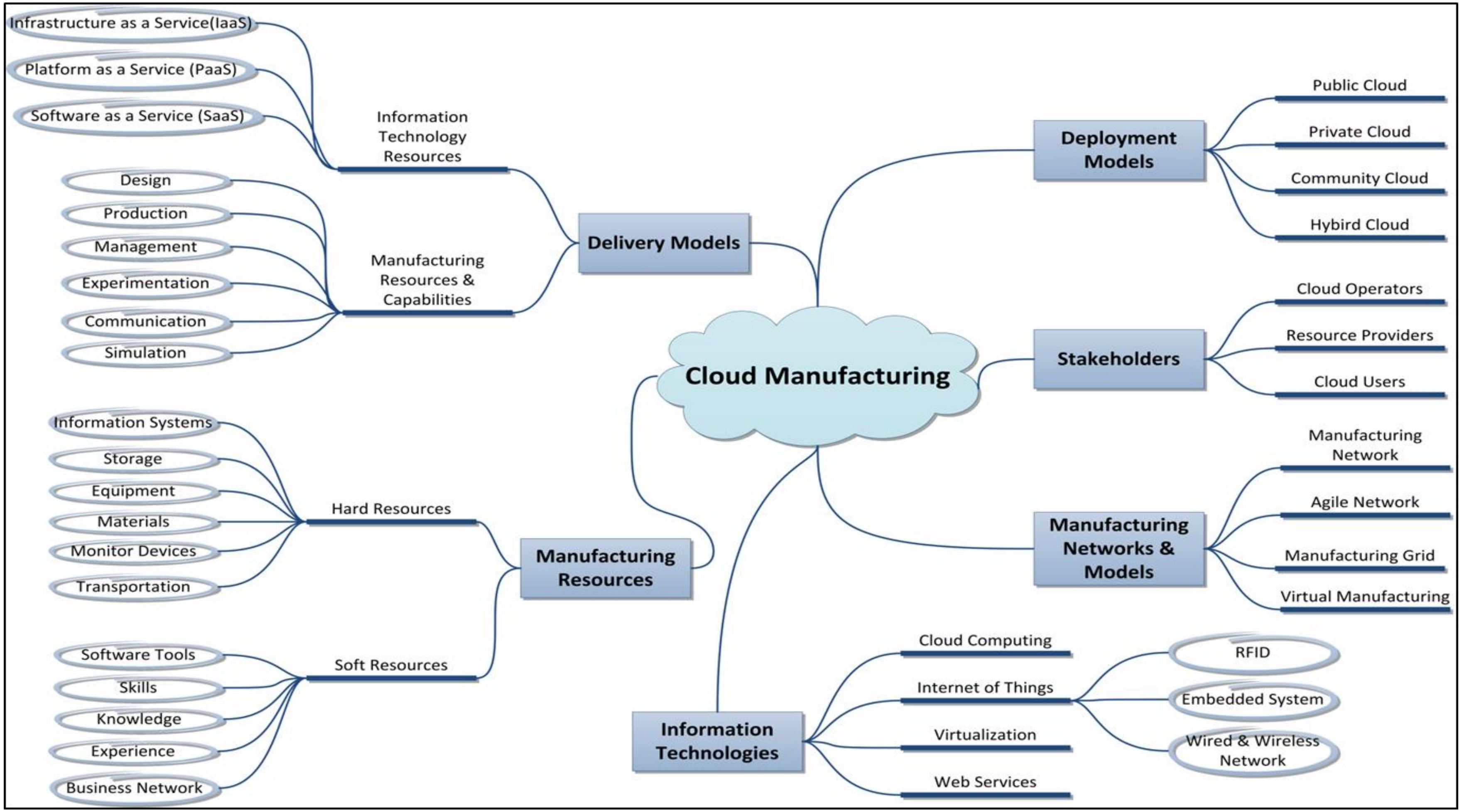


Figure 4-11: Cloud manufacturing taxonomy (Yadekar *et al.,* 2016)

4.4.1 Cloud Manufacturing Deployment Models

There are four types of deployment models in the cloud environment: public cloud, private cloud, community cloud and hybrid cloud (Marston *et al.*, 2011; Tao *et al.*, 2011a; Xu, 2012). Each type is designed for a given situation suitable for the particular enterprise and has its own requirements. cloud manufacturing can use any of four types of deployment models in its architecture to transfer manufacturing resources and capabilities into the cloud manufacturing. Figure 4-12 shows the four deployment models in the cloud environment.

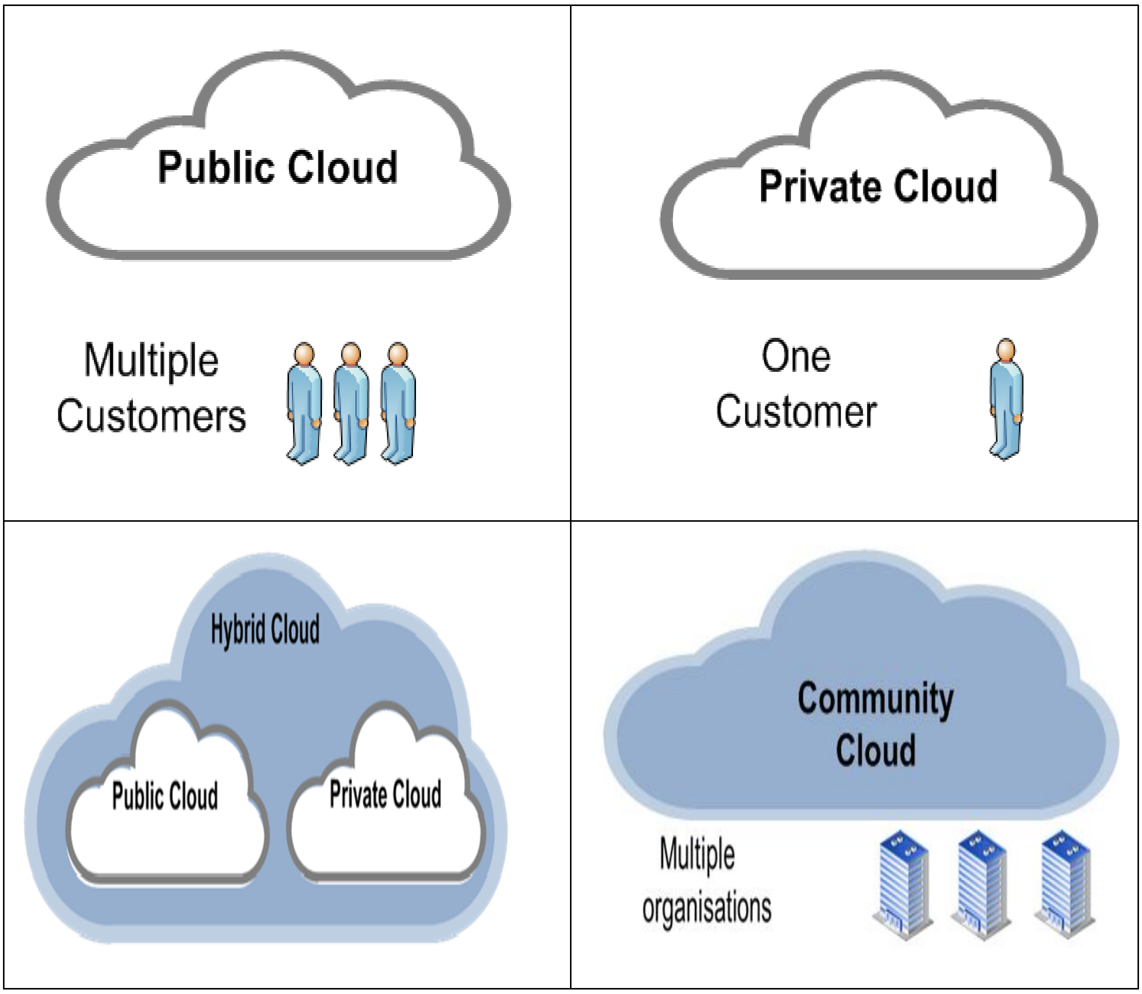


Figure 4-12: Four deployment models

A public cloud is offered services and infrastructure from an off-site, third party service provider via the Internet. All operations in the cloud system (provisioning, maintenance, management, installation, and update) are the service provider's responsibilities. Customers in this deployment model are charged only for service according to their needs. In addition, cloud services are used and shared among different users. The advantage of this kind of cloud is in reducing the cost of (IT) solutions in the enterprise. However, Security and privacy issues are the disadvantages of this type of the deployment model. An example of a public cloud is MFG.com, a marketplace for both buyers who are looking for resources or capability for their product and suppliers that provide material or services.

A private cloud provides an enterprise with the same services and infrastructure as the public cloud, but is managed internally, with only the one organisation using the cloud services. The key advantage of this cloud is the ability to control the cloud infrastructure without third party intervention.

Access for the private cloud is also limited to the organisation's users only. Organisations often prefer using a private cloud for critical data and applications. The major downside of private cloud is the cost. Building and operating a private cloud can be a costly option for organisations, especially SMEs due to up-front capital costs and investments related to private cloud infrastructure (Zhang *et al.*, 2010).

A community cloud is used and supported by several organisations that have the mutual interests and concerns. For example in United Kingdom, the National Health Service (NHS) has begun a pilot scheme to store healthcare data from different sources into the cloud. This scheme will allow patients to share their personal information with General Practitioners (GP) and consultants (Cloud Industry Forum, 2014). While a hybrid cloud consists of two types of cloud, a public cloud and a private cloud. This cloud is used by enterprises to determine how to distribute and share critical information, services and infrastructure within or outside the enterprise. Non-critical data is migrated into a public cloud whereas critical data is migrated into a private cloud (Marston *et al.*, 2011). This cloud provides control for organisations to share their data and applications at different levels of access with others (consumers, suppliers, and partners).

4.4.2 Cloud Manufacturing Delivery Models

There are two classifications of service delivery models in cloud manufacturing: the first type depends on the Information Technology resources (storage, software, server, and network); whereas the second type depends on manufacturing resources and capabilities (design, production, quality control, simulation, transportation, and experimentation) (Wang and Xu, 2013; Wu *et al.*, 2013).

The Information Technology resources type includes three service delivery models: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) (Furht and Escalante, 2010; Yang, Li and Tong, 2012). In IaaS, all hardware (server, storage space, and networking components) that are needed to support all computational operations in the enterprise are owned and controlled by cloud providers. They deliver this service to the enterprise based on enterprise's requirements. PaaS provides the computing platform, which includes the operating system, programming language, and database, to the enterprise as a service. This platform allows developers to create their own software applications by using tools supplied by cloud provider. The SaaS service delivery model provides software applications to the users without the need to purchase, install and maintain the application, where the application is run through the Internet from the cloud (Sudha and Viswanatham, 2013). Information Technology resources delivery models are shown in Figure 4-13.

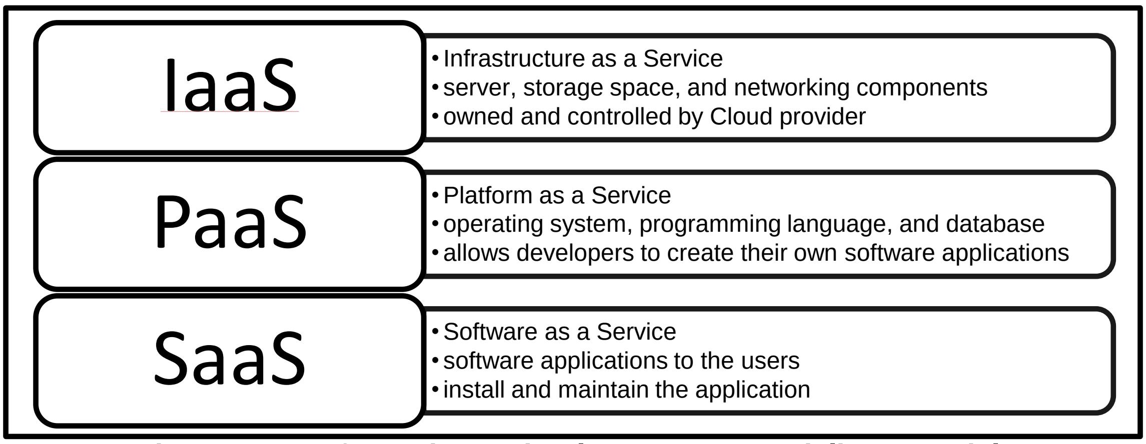


Figure 4-13: Information technology resources delivery models

The other type includes all the manufacturing resources and capabilities involved in aspects of manufacturing can be delivered via a service model for cloud manufacturing users. The service delivery models can be for example, design, production, or communication as services in cloud manufacturing system. These delivery models may result from collaboration among different enterprises (Wang and Xu, 2013). Manufacturing resources and capabilities delivery models are shown in Figure 4-14.

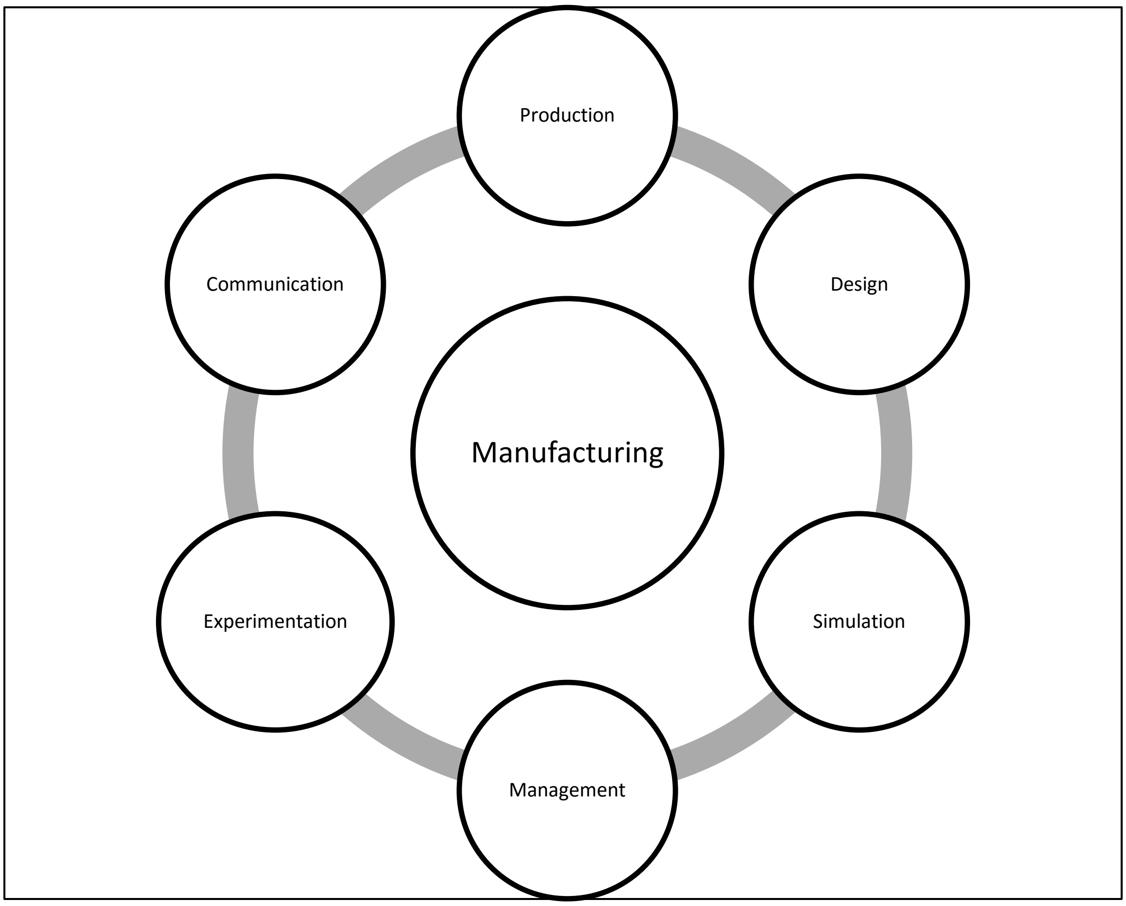


Figure 4-14: Manufacturing resources and capabilities delivery models

4.4.3 Cloud Manufacturing Stakeholders

The primary stakeholders in any typical information system environment are providers who sell, install, license, maintenance the system; and consumers who use, own, maintain and upgrade the system (Marston *et al.*, 2011). However, in a cloud environment, new stakeholders appear and the role of providers and consumers changes. Stakeholders in a cloud manufacturing can be categorised into three main groups: cloud users, cloud resource providers, and cloud operators (Xu, 2012; Wang and Xu, 2013; Wu *et al.*, 2013).

There are two types of users in cloud users, end-users and enterprise users. Both types of users are considered as consumers or organisations subscribed to a service in the cloud manufacturing, and need to access manufacturing resources and/or manufacturing capabilities to conduct a production task.

Cloud resource providers are divided into two groups. Manufacturing resources and manufacturing capabilities providers that are responsible for delivering manufacturing resources and manufacturing capabilities to cloud users. They own and operate manufacturing resources, such as manufacturing equipment, monitor control devices and materials. Also, they possess the experience and knowledge needed for the production process. The second group is Information Technology resources providers that are responsible for delivering computing resources to cloud users. This group offers infrastructure services to facilities accessing computing resources for the users, platform services for developers to develop their own application, and software services to deliver software applications based on the needs of the user.

The last primary stakeholders are cloud operators that own and manage cloud manufacturing, and they are responsible for delivering cloud services to the users. They manage and control all activities in cloud manufacturing from system maintenance to upgrading software applications; adding/removing cloud user account information; monitoring network communication and system performance; and pricing of the cloud services.

4.4.4 Cloud Manufacturing Resources and Capabilities

Manufacturing resources can be divided into two groups: soft resources group, including software, knowledge, skill, experience, and business network; and hard resources group, comprising manufacturing equipment, monitor control devices, materials, transportation, storage, and computational resources (server, software, platform). Manufacturing capabilities refer to ability to transform manufacturing resource into another form (design, production, management, and communications) (Wang and Xu, 2013).

4.4.5 Cloud Manufacturing Information Technologies

Cloud manufacturing is supported by four main information technologies: cloud computing, Internet of Things (IoT), virtualization and Web service. Figure 4-15 shows cloud manufacturing's four main information technologies. Besides cloud computing which mentioned earlier, Internet of Things (IoT) is the computing concept to connect physical objects and automatically exchange data over the Internet by using supporting technologies (Atzori *et al.*, 2012). In other words, it is the ability to connect everyday devices (coffee maker, oven, smart phones, or machine tool) to the internet to interact with other devices. Elements of IoT are: sensing (radio frequency identification), communication technologies (wireless sensors network, embedded system), and Middleware (Gubbi *et al.*, 2013). The radio frequency identification (RFID), which is used to identify tags attached to an object and transfer the data to the receiver wirelessly; wireless sensors network, which consists of distributed autonomous sensors used to monitor and for remote sensing of objects; and an embedded system, which is microprocessor system built into devices for specific functions and used to give real-time data. The Middleware is computer software that mediates communication between technological and application levels.

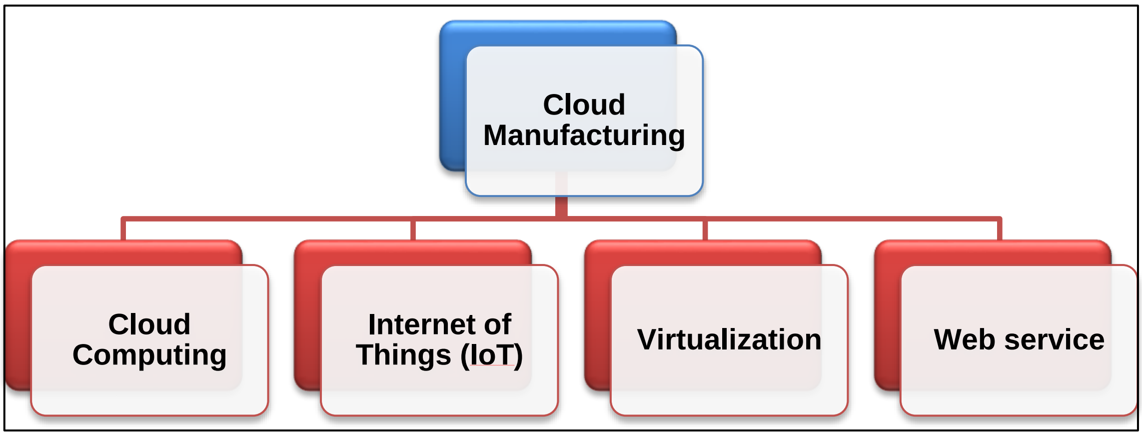


Figure 4-15: Cloud manufacturing supported information technologies

A virtualisation is a computing approach to creating a multiple virtual version of a single physical resource or capability, such as a server, storage device, network or even an operating system, to share it with other on the network (Bourguiba *et al.*, 2012). It allows the sharing of resources among cloud users, which results in the minimising of the cost of using physical resource or capability, for the users. Also, another benefit of virtualisation is the ability to operate and support legacy systems that require old operation system, hardware, and software libraries (Wang *et al.*, 2010).

With the evolution of communication networks and Information Technologies, a new technology has emerged, called “Web service.” Web service is a software system that provides communication between different types of machines over the Internet without requiring human interaction (Kanwar *et al.*, 2010). A significant difference between Web services and websites is data communication. Whereas in websites, humans interact with the website and access the data, in Web services, the data is accessed by software application. Web service components are Extensible Markup Language (XML), which creates tags for the data; Standard Object Access Protocol (SOAP), which transfers the data; Universal Description, Discovery and Integration, which provides the status of services; and Web Services Definition Language (WSDL), which describes the services.

4.4.6 Manufacturing Networks and Models

Due to global competition and rapid growth of communication networks and Information Technology, many enterprises rely on a manufacturing Network. This type of network allows manufacturing enterprises to communicate with suppliers and customers and exchange detailed data with them (Wiendahl and Lutz, 2002). Manufacturing Networks consist of original equipment manufacturer (OEM) plants, dealers, and suppliers which may be geographically dispersed (Mourtzis *et al.*, 2013). The benefit of using a manufacturing Network is the ability to integrate both large enterprises and SMEs characteristics together; for example, critical mass in large enterprises and niche markets in SMEs (Butala and Sluga, 2006).

Agile manufacturing can be described as ‘‘the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services” (Gunasekaran, 1998). This manufacturing model concentrates on customised products rather than mass production. It can respond to expected and unexpected changes in the market and customer demands (Panchal and Schaefer, 2007). Agile manufacturing characteristics are: producing high quality customized products; providing products and services with high information and value-added content; mobilization of core competencies; interacting with social and environmental issues; installation of various technologies; and dealing with uncertainty (Yusuf *et al.*, 1999).

The concept of a manufacturing Grid is to combine different enterprises together in order to join their manufacturing resources that are distributed in heterogeneous systems and multiple sites, into one manufacturing system (Tao *et al.*, 2010). Manufacturing Grids depend on three leading technologies (grid technologies, Information Technologies, computer and advanced management technologies) to offer access to the manufacturing services that are needed by the users. Distributed, dynamic, autonomous, and transparent manufacturing resources are the characteristics of a manufacturing Grid (Tao *et al.*, 2011b).

4.4.7 Taxonomy Validation

To validate the taxonomy, an interview with two experts in Information Technology and cloud technology fields was conducted to capture their views after presenting the taxonomy. The following questions were posed to the experts:

1. Would the taxonomy be useful for researchers and enterprises that using or considering adopting cloud manufacturing?
2. Are the concepts and terminology in the taxonomy well explained and easy to understand?
3. What are improvements are needed for the taxonomy?

The experts agreed that the taxonomy is well-organised and covers the most important aspects of cloud manufacturing. The description and explanation are comprehensive and easy to understand. The experts' suggestion for improvement the taxonomy is to add real-life examples in each category of the taxonomy.

4.5 Chapter Summary

This chapter has shown what cloud manufacturing is by providing an overview of the manufacturing development from traditional manufacturing to cloud manufacturing, disturbing a questionnaire to the cloud's users to capture requirements; measure the industrial awareness; and identify challenges of cloud manufacturing. The outcome from this chapter contributes to the cloud manufacturing literature by providing a comprehensive taxonomy of cloud manufacturing, and understanding the concept of cloud manufacturing.

Also, Finding from this taxonomy can describe cloud manufacturing as manufacturing model that provides a platform for collaborations between different users (consumers, manufactures, supplies) to achieve their goals by using the latest information technologies (cloud computing, IOT, virtualisation, Web service) and advanced communications networks (Manufacturing Network, Agile Manufacturing, Manufacturing Grid). This model have three main stakeholders (cloud users, cloud resource providers, cloud operators), and consists of four different deployment models (public cloud, private cloud, community cloud, hybrid cloud) and two delivery models.

5 UNCERTAINTY MANAGEMENT FRAMEWORK

5.1 Introduction

The previous chapter provided a better understanding of cloud manufacturing by exploring the concept, introducing a taxonomy, and identifying the challenges of cloud manufacturing. Those findings are the key elements in the development of the uncertainty management framework in this research. This chapter presents the proposed framework to manage the uncertainties in cloud manufacturing. Additionally, a process to identify uncertainties has been developed to help decision makers identify uncertainties in cloud manufacturing.

The structure of the chapter as follows: Section 5.1 introduces an uncertainty management framework; Section 5.2 describes the development of the uncertainty management framework; Section 5.3 introduces the process of identifying uncertainties in the cloud manufacturing; and finally Section 5.4 presents the chapter summary. Figure 5-1 shows the chapter structure.

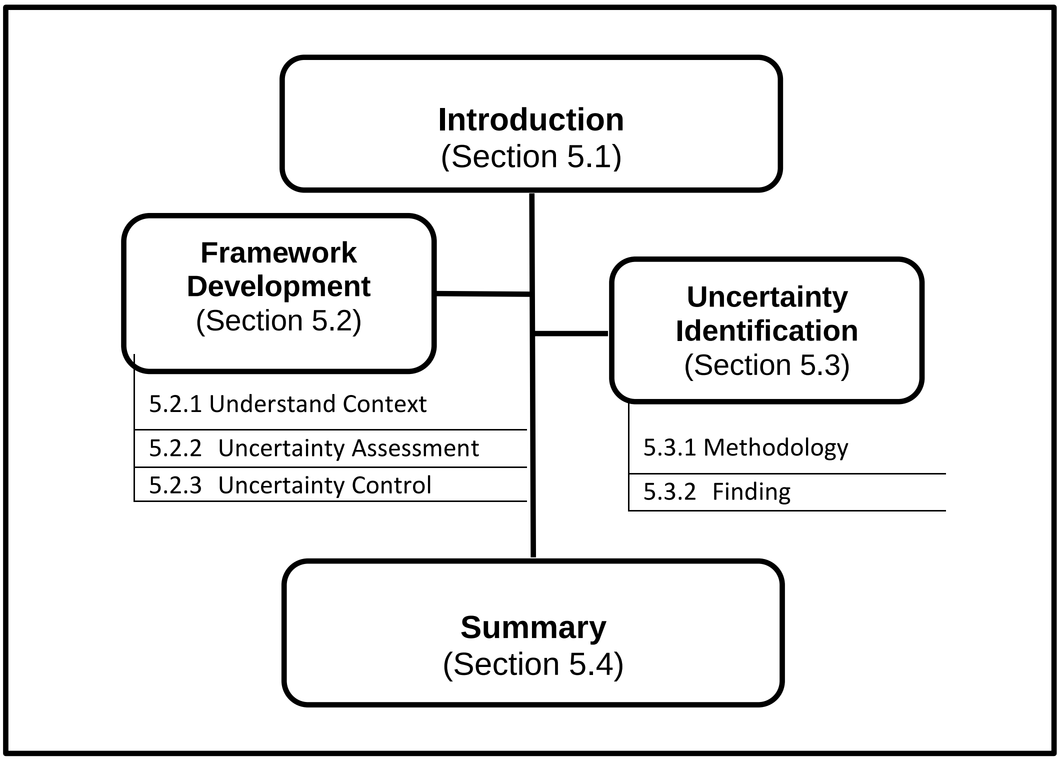


Figure 5-1: Chapter structure

5.2 Framework Development

This section describes the development of the uncertainty management framework. This framework offers guidance for decision makers to deal with uncertainty in cloud manufacturing at the adoption level as well as the implementation level. The framework provides a detailed step-by-step approach to understand, highlight, analyse, quantify, and control the most critical uncertainties. The framework comprises a cloud manufacturing taxonomy (Chapter 4), the process to identify uncertainties in cloud manufacturing (Section 5.3), and an approach to uncertainty assessment and control (Chapter 6). The deliverables of the framework are: a cloud manufacturing taxonomy; a list of uncertainty factors; a process to prioritise and quantify uncertainties by using Simple Multi-Attribute Rating Technique (SMART) and fuzzy rule-based system; and a knowledge base to provide strategies and solutions to control uncertainties. An overview of the framework is shown in Figure 5-2.

5.2.1 Understand the Context

A first step to developing the framework was to explore and understand the concepts, terminology, and relationships in all aspects related to this research. This phase involved a comprehensive literature review on the ideas of cloud manufacturing, cloud computing, uncertainty, risk, uncertainty management, uncertainty assessment, and risk management. Interaction with members of academia and industry experts occurred by distributing a survey. Members of the CAPP project were met and interviewed.

The outputs of this phase included an understanding of the concept of cloud manufacturing and a cloud manufacturing taxonomy, which provided a description and classification of all aspects of cloud manufacturing in a well-organised structure, and identified challenges and problems that exist in cloud manufacturing. These determined how the researcher was to approach the uncertainties in cloud manufacturing. Understanding the context phase is covered in detail in Chapters 2 and 4.

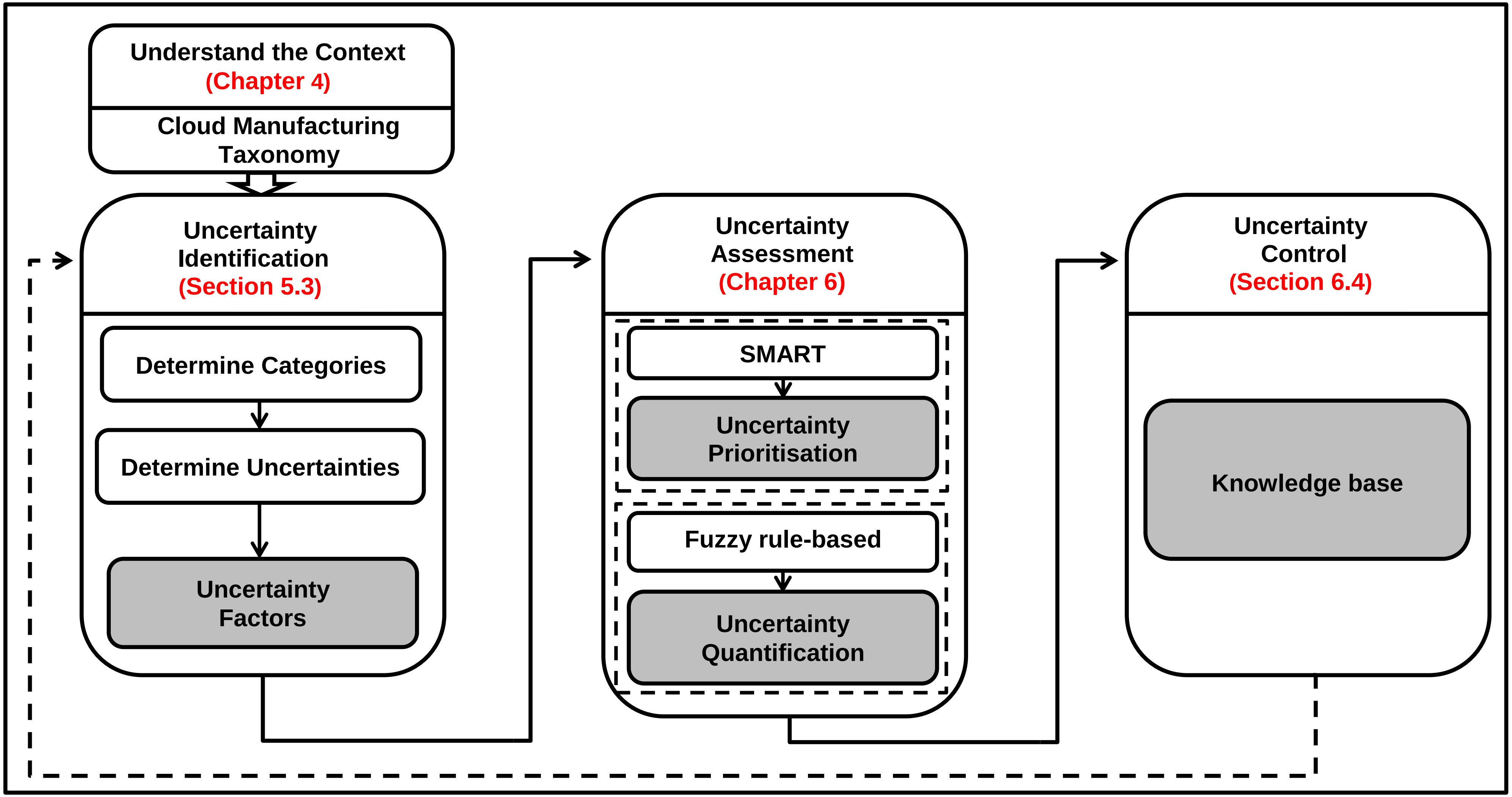


Figure 5-2: Framework overview

5.2.2 Uncertainty Assessment

After identifying all potential uncertainty factors in cloud manufacturing in phase (1) of uncertainty management, there is a need to evaluate each uncertainty factor. This phase provides a process to prioritise and quantify uncertainty factors. The assessment delivers two outputs: prioritisation of each identified uncertainty and quantification of security and privacy uncertainty factors. This assessment can used to determine strategies and decisions on how to deal with uncertainty in cloud manufacturing.

The process of uncertainty assessment is conducted in two essential steps: estimate the importance of uncertainty (weight), and then rate uncertainties according to value of weight for each uncertainty in the cloud manufacturing; determine the most important uncertainty factors in the security and privacy category and then quantify those uncertainty factors with a knowledge base that provides solutions to deal with those uncertainties. The author has applied Simple Multi-Attribute Rating Technique (SMART) (Edwards, 1971) to prioritise uncertainty factors and fuzzy rule-based system to quantify security and privacy uncertainty factors. More details are presented in Chapter 6.

5.2.3 Uncertainty Control

This phase provides recommendations and solutions to deal with uncertainties by applying mitigation strategies and monitoring remaining uncertainties in cloud manufacturing. According to Udovyk and Gilek (2013), there are three main mitigation approaches in uncertainty management: reducing, controlling, and coping strategies.

A reducing strategy considers uncertainty that comes from a lack of knowledge (Epistemic uncertainty) and can be mitigated through adding more information and conducting more research. A controlling strategy considers different types of uncertainties that need control and can be mitigated through applying scientific methods, such as quantification methods, priorities, and expert elicitation. A coping strategy considers uncertainty as that inherent property of complex systems that are irreducible (Aleatory uncertainty) and can be mitigated through knowledge description, stakeholder involvement, NUSAP, and uncertainty matrix.

After reviewing the three main mitigation strategies, the researcher selected the controlling strategy based on the aim and objectives of this research. More details are presented in Section 6.4.

5.3 Uncertainty Identification

This phase provided a process to identify the types and sources of uncertainties that exist in cloud manufacturing. It is considered the first stage in uncertainty management, with documentation of uncertainties in the early stage of the project being an essential step to provide a knowledge base for the uncertainties.

To begin with, the related literature of both main concepts, cloud manufacturing and uncertainties, was explored. Next, published technical reports related to issues, problems, challenges, and risks of cloud computing technology implementation in manufacturing (in particular), along with other sectors were examined. Then, interaction with academia and industry was made by distributing a questionnaire and conducting unstructured and semi-structured interviews. Finally, validation of the finding occurred by conducting interviews with experts.

Uncertainty identification is based on the same principles as risk identification - focus is more on uncertainty characteristics rather than in risk identification where focus is only on threats (Ward and Chapman, 2003). There are various methods involved in uncertainty identification. Uncertainty can be identified by interviews, surveys, Delphi technique, observation, brainstorming, documentation (academia, published technical reports), SWOT analysis, diagramming techniques and checklists. The result of this process is an uncertainty factors list, which contains a detailed description of uncertainties in cloud manufacturing. The outcome of this phase is critical for the development of the framework. Its delivers uncertainty factors list, which contains a detailed description of uncertainties and their categories in cloud manufacturing.

Additionally, the selection of categories was based on the categories in the related literature. The data security and privacy category considers factors that result in a loss of confidentiality and integrity in cloud manufacturing. The technical category is defined as the failures associated with the technologies and services provided by cloud manufacturing. The management category considers factors that affect the pricing in the cloud and the ability to access, control and manage the cloud.

5.3.1 Methodology for Uncertainty Identification Process

The identification process methodology consists of three phases: develop, refine, and finalise the uncertainty factors list. The first phase develops a list of uncertainty factors through literature, brainstorming, and survey. The second phase refines the list of uncertainty factors through Delphi survey, interviews, and workshops. The concluding phase finalises the list of uncertainty factors through interviews and group discussions. Figure 5-3 shows a detailed methodology for identifying uncertainty factors in cloud manufacturing.

5.3.2 Uncertainty Factors List Preparation

Besides conducting a comprehensive review of previous studies and reviewing published technical reports, distribution of an online questionnaire was used in this phase. The initial uncertainty factors list clearly shows that there is no emphasis on cloud manufacturing, in particular, requiring an in-depth interaction with industry to refine the list.

- **Literature review**

An extensive literature review was conducted to capture the challenges of cloud technology in manufacturing. The focus of this method was on literature related to cloud technology implementation in manufacturing and its challenges. In order to identify publications related to cloud technology in manufacturing, a search in both academic databases and search engines was conducted and limited to the specific keywords: cloud computing, cloud manufacturing, cloud technologies, cloud risks, cloud uncertainty, cloud security, and manufacturing.

The majority of the relevant studies in the literature indicated that there is no association between identified uncertainty factors and research topic due to the novelty of the cloud manufacturing concept. The identified uncertainty factors either belong to cloud computing or manufacturing in general.

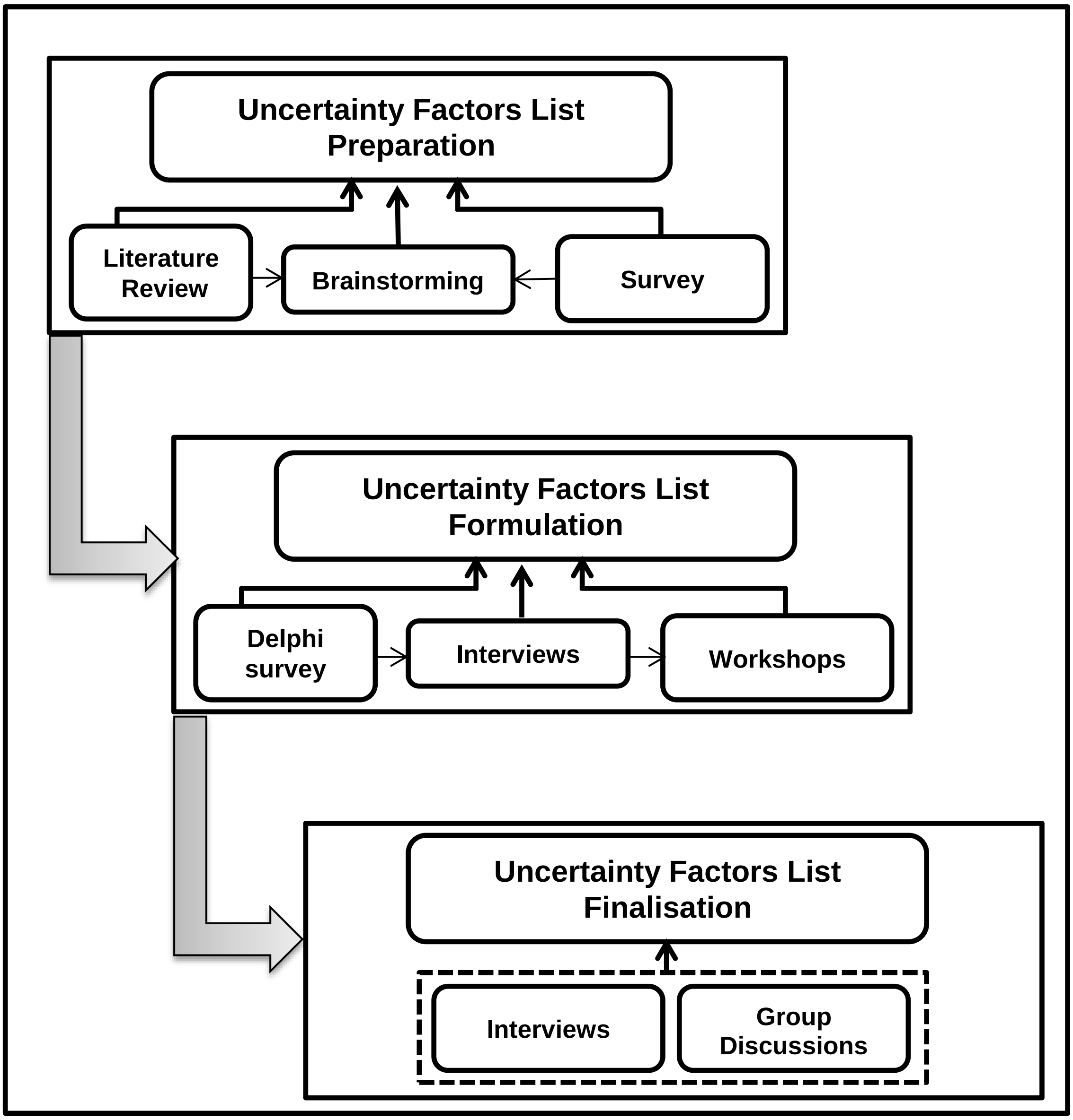


Figure 5-3: Uncertainty identification methodology

- **Questionnaire**

A pilot questionnaire with a mix of open-ended, closed, and scaled questions was designed. This was based on the literature review, participation in online group discussions (LinkedIn) and previous interviews. The aim of this questionnaire was: to capture requirements for those using or considering adopting cloud computing technology in their enterprises; to measure the awareness of cloud computing technology among individuals and enterprises; and to identify the challenges of cloud computing technology in the manufacturing environment.

The pilot questionnaire was distributed to a sample of four individuals (two experts and two researchers) to check the wording, codes of closed questions, and questionnaire instructions. The feedback from the pilot questionnaire resulted in adding multiple choice answers for some of the questions such as Question 3, as illustrated in Figure 5-4.

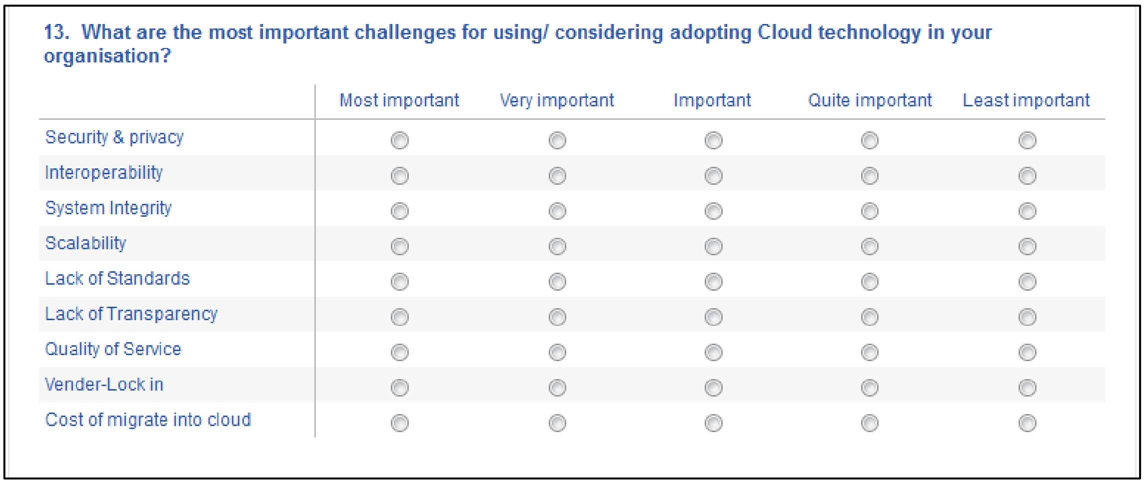

3. What is your role in your organisation:

Job Title

- [ ] Management
- [ ] IT specialist
- [ ] Researcher
- [ ] Other (please specify):

Figure 5-4: Cloud manufacturing questionnaire - question 3

Also, other questions such as Question 13 was re-worded to be more understandable for participants, as shown in Figure 5-5.

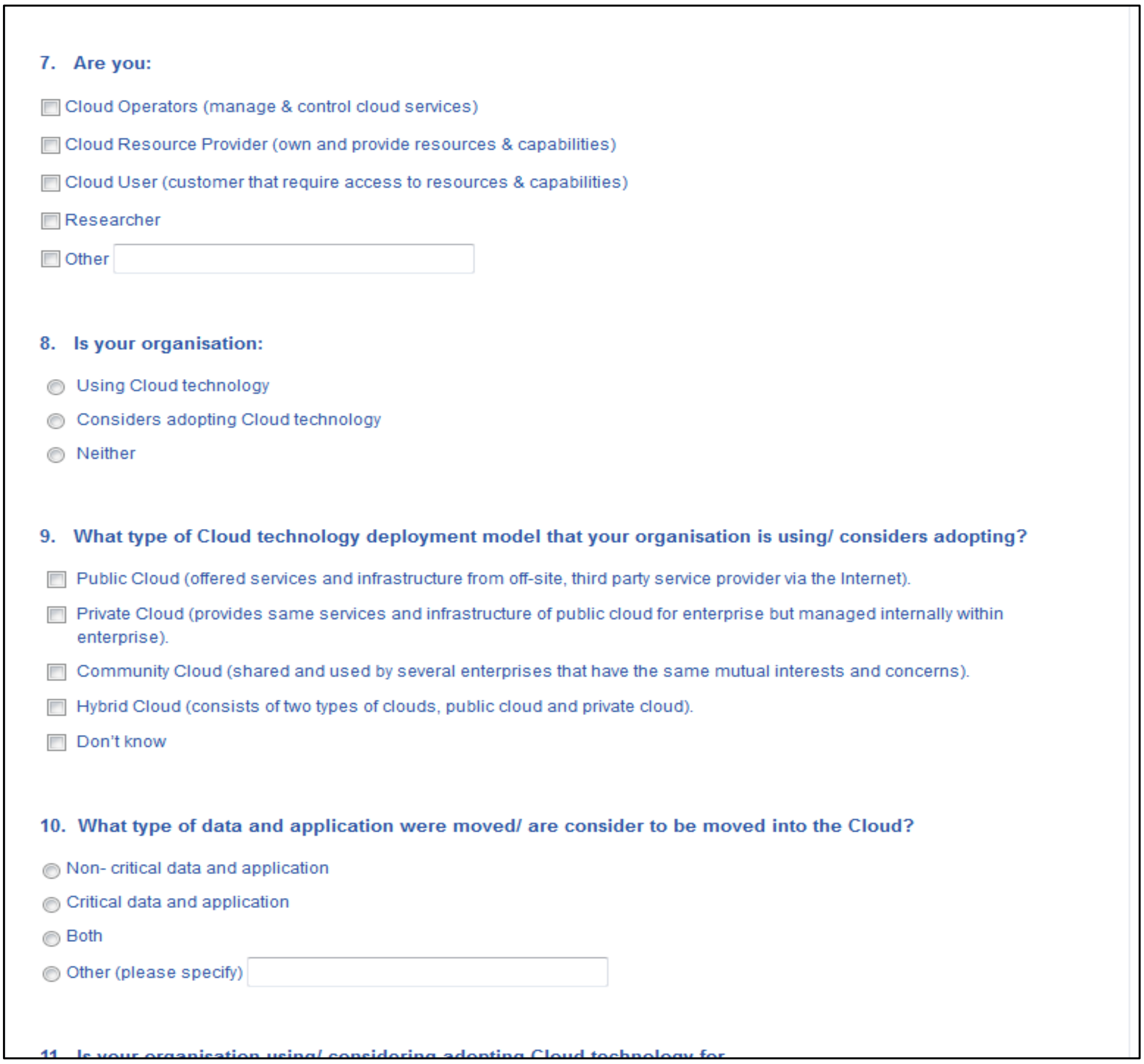

13. What are the most important challenges for using/ considering adopting Cloud technology in your organisation?

	Most important	Very important	Important	Quite important	Least important
Security & privacy					
Interoperability					
System Integrity					
Scalability					
Lack of Standards					
Lack of Transparency					
Quality of Service					
Vender-Lock in					
Cost of migrate into cloud					

Figure 5-5: Cloud manufacturing questionnaire - question 13

The final design of the questionnaire includes two sections with a total of 13 questions (See Appendix B.1 for full questionnaire). The first section shows the details of the respondent and their organisation. The second section concentrates on the use or adoption of cloud technology in the respondent's organisation. Figure 5-6 shows a snapshot of the finalised questionnaire.

The questionnaire was designed by using Cranfield University's Qualtrics survey tool to create the survey instrument and distributed online via email. The email included an invitation to participate in this online survey, an explanation of its aims, a questionnaire link, approximate time to complete the questionnaire, and time-frame to return the questionnaire (which was one month). More details are presented in Chapter 4.



7. Are you:

- Cloud Operators (manage & control cloud services)
- Cloud Resource Provider (own and provide resources & capabilities)
- Cloud User (customer that require access to resources & capabilities)
- Researcher
- Other

8. Is your organisation:

- Using Cloud technology
- Considers adopting Cloud technology
- Neither

9. What type of Cloud technology deployment model that your organisation is using/ considers adopting?

- Public Cloud (offered services and infrastructure from off-site, third party service provider via the Internet).
- Private Cloud (provides same services and infrastructure of public cloud for enterprise but managed internally within enterprise).
- Community Cloud (shared and used by several enterprises that have the same mutual interests and concerns).
- Hybrid Cloud (consists of two types of clouds, public cloud and private cloud).
- Don't know

10. What type of data and application were moved/ are consider to be moved into the Cloud?

- Non- critical data and application
- Critical data and application
- Both
- Other (please specify)

11. Is your organisation using/ considering adopting Cloud technology for

Figure 5-6: Snapshot of finalised questionnaire

- **Industry Reports and Documents**

Gathering information and documents available to the public from well-known organisations that are interested in cloud computing technology via the companies' websites was an important source of data collection.

The selected industrial reports included: "*Top Threats to Cloud Computing V1.0*" from Cloud Security Alliance (CSA), "*NIST Cloud Computing Standards Roadmap*" and "*Cloud Computing Synopsis and Recommendations*" from National Institute of Standards and Technology (NIST), "*Cloud Computing: Benefits, risks and recommendations for information security"* from European Network and Information Security Agency (ENISA), "*Unleashing the Potential of Cloud Computing in Europe"* from the European Commission, "*Cloud computing issues and impacts*" from Global Technology Industry, and "*Moving to the Cloud: An Introduction to Cloud Computing in Government"* from the IBM Centre for the Business of Government.

- **Brainstorming**

Brainstorming as an identification technique in uncertainty management can generate new ideas regarding uncertainty factors in cloud manufacturing. Additionally, it provides a well organised structure to present those uncertainties, and it is quite quick and easy to set up. The Author conducted a group session with two other Ph.D. researchers to identify the maximum amount of uncertainty possible in cloud manufacturing.

5.3.3 Uncertainty Factors List Formulation

The initial uncertainty factors list was presented with uncertainty factors from a broad perspective in cloud computing and Information Technology, but without the manufacturing perspective. In this phase, the author interacted with both academic and industry experts to capture the uncertainty factors within the cloud manufacturing perspective. The methodology to refine the initial list involved distribution of a Delphi survey to fifteen active researchers in the cloud manufacturing research field, and conducting interviews and participating in workshops with experts in the Information Technology field and members of the CAPP-4-SMEs project.

- **Delphi Survey**

This approach depends on a combination of literature review and expert elicitation. Fifteen active researchers in the cloud manufacturing research field were sourced using the online academic search engines. The survey was distributed through email, and was composed of two rounds, where each round was distributed online on a separate occasion.

In the first round, the active researchers were asked to articulate their thoughts and opinions on what are the potential uncertainties in cloud manufacturing. After analysing responses from Round 1, a summarised table of uncertainty types was created. For each uncertainty type, a one-two line description and comments by participants were included. In the second round, the active researchers were asked to consider revising their earlier input after reviewing the feedback of the other participants by add/delete/modify of any uncertainty type.

- **Interviews and Workshops**

A set of interviews and workshops in both academia and industry were conducted to investigate problems and challenges, and to understand the role of uncertainties in cloud manufacturing. Interviews were either face-to-face, online, by phone, or email. The interview process was based on both unstructured and semi-structured questions. The industry interactions were with experts in Information Technology field and members of the CAPP-4-SMEs project that is supported by the European Union Seventh Framework Programme. An overview of interviews and workshops with the experts is shown in Table 5-1:

Expert	Role	Experience	Type of Meeting
CAAP member	Principal Scientist	More than 30 years in both industry and academia	Interview / Workshops / Weekly online discussions
CAAP member	Principal Scientist	13 years	Interview / Workshops / Weekly online discussions
Company A	Manager	12 years	Interview
Company B	Division Manager	26years	Emails / Workshops / Weekly online discussions
Trade association X	CEO	25 years	Emails / online discussions
MOD-Kuwait	Head of Department	12	Interview
MOT-Kuwait	Developer	18	Interview
MOF-Kuwait	Head of Department	13	Interview
MOF-Kuwait	Developer	7	Interview
Telecom. Company	Network Engineer	13	Interview
Service Company	Network consultant	9	Interview
CAPP Project	Various	Various	Weekly online discussions/ Workshops

Table 5-1: Overview of interviews and workshops

5.3.4 Uncertainty Factors List Finalisation

Firstly, the uncertainty factors were presented to two experts with knowledge in cloud manufacturing and Information Technology. The two experts were asked to provide feedback by adding to/deleting/modifying each uncertainty factor. Additionally, the uncertainty factors were presented to members of the CAPP project followed by a group discussion. After interviews and group discussion, a finalised list of 32 uncertainty factors was created.

5.3.5 Findings

A summary of 32 uncertainty factors has been identified and categorised into three categories (Yadekar *et al.*, 2014b, 2016). The category selection was based on the categories in the related literature. The data security and privacy category considers factors that allow loss of confidentiality and integrity in cloud manufacturing systems. The technical category is defined as the failures associated with the technologies and services provided by cloud manufacturing. The management category considers factors that affect the pricing in the cloud and the ability to access, control, and manage the cloud. Table 5-2 shows a finalised uncertainty factors list.

Category	Uncertainty factors
Data Security & Privacy	Data Breach - Data Control - Data Location - Data Loss or Leakage - Insecure Cloud Services Interfaces - Applications Security - Cloud Services Interfaces Data Transmission Security - Cloud Services Interfaces Development Security - Remote Access Cloud Services Security - Intellectual Property (IP) Protection - Encryption Levels
Technical	Scalability – Bandwidth - Cloud Service Availability – Hardware/Machine Availability - System Integrity - Data Interoperability/Standardisation - Machine Protection – Latency - Fault-tolerance - Revision Request - Disaster Recovery – Vender Lock-in
Management	Authentication Mechanism - Administrative Management - Permission Control - User Boundary - Quality Control and Assurance – Training – Standards - Unexpected Cost/Price Changing - Quality of Service

Table 5-2: Finalised uncertainty factors list

5.3.5.1 Data Security and Privacy related uncertainty factors

Data Breach: The uncertainty is related to the data breach from outside/inside users into the cloud by hacking passwords and key cracking and hosting malicious data.

Data Control: The uncertainty is related to loss of physical control over data.

Data Location: The uncertainty is related to the location of data that may create conflict with regulations and data privacy laws in the company’s country.

Data Loss or Leakage: The uncertainty is related to the ability of deletion or alteration of records without a backup, loss of an encoding key may result in effective destruction, and unauthorised parties must be prevented from gaining access to sensitive data.

Insecure Cloud Services Interfaces: The uncertainty is related to anonymous access and/or reusable tokens or passwords, clear-text authentication or transmission of content, inflexible access controls or improper authorizations, limited monitoring capabilities.

Applications Security: The uncertainty is related to ability to protect software applications from privacy, IP hacks, cloning security.

Cloud Services Interfaces Data Transmission Security: The uncertainty is related to transmission clear error and message handling between cloud services interfaces.

Cloud Services Interfaces Development Security: The uncertainty is related to cloud service interfaces created by certain development tool chains like ASP.NET, JAVA, can be insecure since not known security measures that are used in the applications.

Remote Access Cloud Services Security: The uncertainty is related to remote access cloud services without affecting encryption/decryption mechanism in the cloud.

Intellectual Property (IP) Protection: The uncertainty is related to the ability to prevent hacking/Phishing attempts from competition.

Encryption Levels: The uncertainty is related to the ability to determine the encryption type for each data type, process, etc.

5.3.5.2 Technical related uncertainty factors

Scalability: The uncertainty is related to the ability to request additional resources or services.

Bandwidth Capacity: The uncertainty is related to the ability to collect real-time data from manufacturing resources to the server. This results in huge demands on network bandwidth capability.

Cloud Service Availability: The uncertainty is related to network outage and system failures or inability to access cloud services due to lack of network connectivity.

Hardware/Machine Availability: The uncertainty is related to hardware/ machine availability when multiple users are querying the same machine in parallel; how to guarantee the availability and balance the workloads.

System Integrity: The uncertainty is related to the ability to partition access rights to each stakeholder group.

Data Interoperability/Standardisation: The uncertainty is related to the ability to deal with different CAD formats on the market; they may or may not be readable to the cloud.

Machine Protection: The uncertainty is related to the ability to protect manufacturing physical resources, e.g. machines, robots.

Latency: The uncertainty is related to time delays that cloud services experience when processing requests.

Fault-tolerance: The uncertainty is related to the ability of a system to continue to operate in the event of the failure of some of its components.

Revision Request: The uncertainty is related to the ability of design/manufacturing request needs to be changed, according to the service provider; how to process and who is responsible.

Disaster Recovery: The uncertainty is related to the ability to recover cloud services after a natural disaster, hardware theft, and electronic mishaps.

Vender Lock-in: The uncertainty is related to the inability of a customer to move their data and/or programs away from a cloud computing service provider.

5.3.5.3 Management related uncertainty factors

Authentication Mechanism: The uncertainty is related to secure authentication methods to access cloud services.

Administrative Management: The uncertainty is related to administrative controls specifying who can perform data related operations such as creation, access, disclosure, transport, and destruction.

Permission Control: The uncertainty is related to permission to share manufacturing resources, and different user's access to various resources. A strategy is needed to confirm the resource access to various levels of users.

User Boundary: The uncertainty is related to how much data/resource the user can access; how to protect resources from unwanted effects, operations, or other users.

Quality control and assurance: The uncertainty is related to the monitoring and document quality of services provided through the cloud.

Training: The uncertainty relates to training staff for cloud services.

Standards: The uncertainty is related to standards for interoperability between cloud services and in-house infrastructure, and the need to understand the responsibilities of each party.

Unexpected Cost/Price Changing: The uncertainty is related to how the cloud service is priced. What if the cost of service is changed in the middle of service?

Quality of Service (QoS): The uncertainty is related to the ability to provide a guarantee of performance, availability, and security. Manufacturing resource or service is changing along with time, as well as its manufacturing resource or service request.

5.4 Chapter Summary

This chapter proposed a framework to manage uncertainties in cloud manufacturing. This framework offers new insights for decision makers on how to deal with uncertainty at the adoption and implementation stages of cloud manufacturing. The framework enables organisations, who are trying to adopt or implement cloud manufacturing, to understand the role of uncertainty in a cloud manufacturing system, understand cloud manufacturing itself, and provide solutions to deal with the uncertainties.

In this chapter, the author explained the framework's components, beginning with understanding the context and uncertainty management phases. Additionally, this chapter demonstrated the steps to develop a process to identify uncertainties in cloud manufacturing. The process provided a list of identified uncertainties in cloud manufacturing and categorised them into three categories: data security and privacy category, technical category, and management category.

6 UNCERTAINTY ASSESSMENT AND CONTROL

6.1 Introduction

With Information Technology revolutionising manufacturing industry, uncertainty assessment is becoming an important tool to understand and manage uncertainties. It is also essential in predicting future outcomes and behaviours in cloud manufacturing, as well as allowing stakeholders to make better decisions. The aim of this chapter is to assess and create a knowledge base for uncertainty factors in cloud manufacturing. The assessment is conducted by applying Simple Multi-Attribute Rating Technique (SMART) (Edwards, 1971) to prioritise uncertainty factors, and a fuzzy rule-based system (FRBS) to quantify security and privacy uncertainty factors.

The structure of the chapter as follows: the chapter aim and methodology are introduced in section 6.1 and section 6.2. Next, sections 6.3 and 6.4 describe the processes of uncertainty prioritisation and uncertainty quantification. Then, section 6.5 demonstrates the development of a knowledge base that provides recommendations and solutions to deal with uncertainties in cloud manufacturing. Finally, section 6.6 presents a chapter summary.

6.2 Chapter Methodology

Figure 6-1 illustrates the detailed methodology for uncertainty assessment in cloud manufacturing. The methodology is divided into two phases. Firstly, the SMART technique was used to prioritise uncertainties based on their weight (importance) in cloud manufacturing. During this phase, all uncertainties were identified and cloud manufacturing's dimensions were determined. The SMART technique is then applied to deliver a ranking system for uncertainties in cloud manufacturing. In the second phase, a fuzzy rule-based system (FRBS) was used to quantify security and privacy uncertainty factors. During this phase, the most important security and privacy uncertainty factors were identified as factors that influence the information security model in the cloud manufacturing. The FRBS is applied to represent, characterise, and analyse security and privacy uncertainty factors in terms of fuzzy rules. Finally, a knowledge base was constructed for security and privacy uncertainty factors in terms of confidentiality, integrity, and availability in cloud manufacturing.

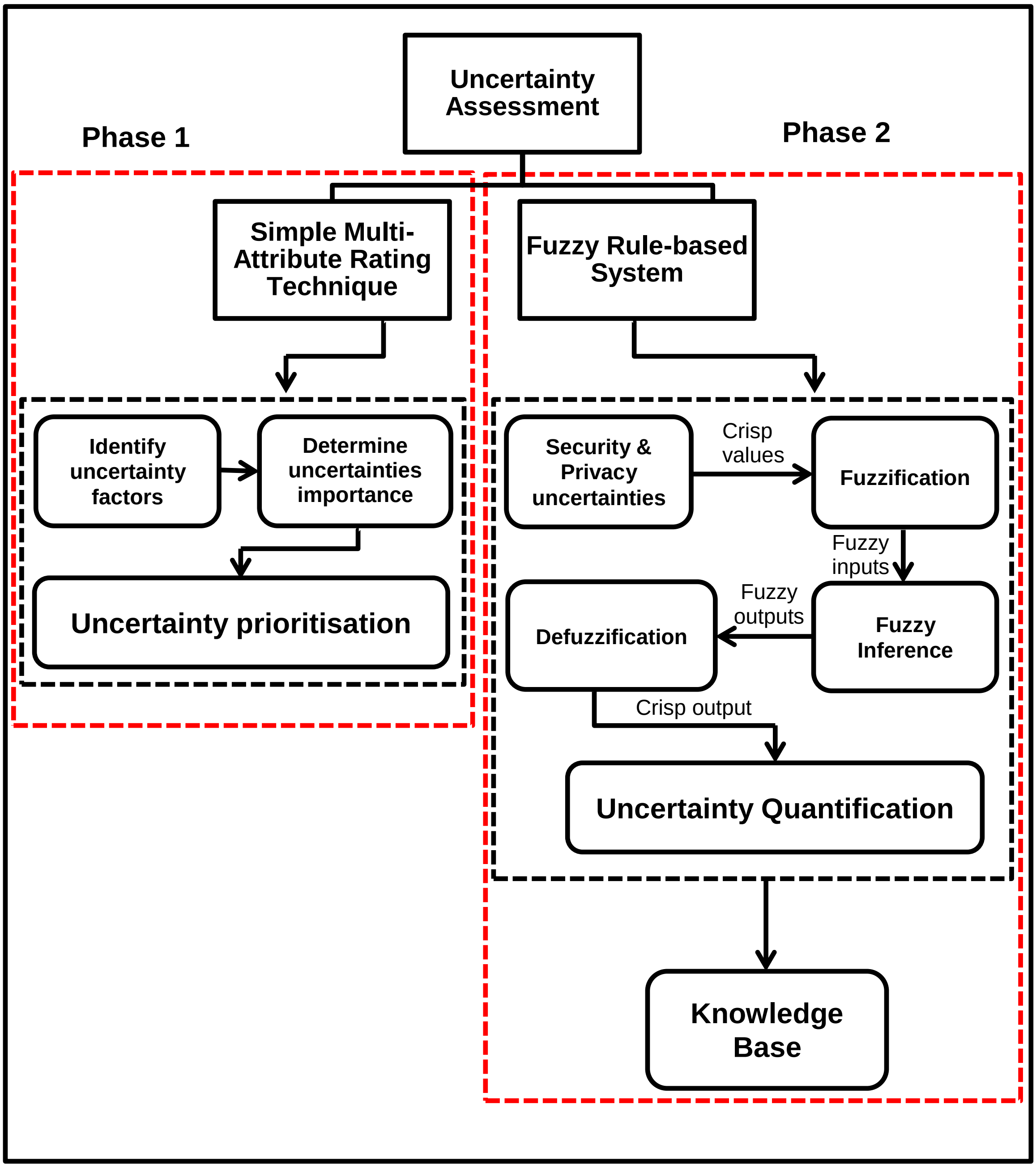


Figure 6-1: Uncertainty assessment methodology

6.3 Phase 1: Uncertainty Prioritisation

After identifying potential uncertainty factors, there is a need to evaluate each uncertainty to understand the rule of each uncertainty factor within cloud manufacturing. This evaluation delivers a ranking for the various uncertainties that is then used to determine strategies and decisions on how to deal with uncertainty in cloud manufacturing. The process of uncertainty prioritisation is conducted in three essential phases: identify all potential uncertainties in the cloud manufacturing; estimate the importance of uncertainty (weight); rank uncertainties according to the value of weight for each uncertainty in cloud manufacturing.

6.3.1 Methodology

Initially, a combination of a literature review (journal papers, reports and documents), interviews, a questionnaire, a Delphi survey, and workshops with experts was used in this research in order to identify uncertainties and to determine the most critical dimensions in cloud manufacturing (Yadekar *et al.*, 2016). From this, a total of 32 potential uncertainty factors were identified, with four important dimensions: security, performance, cost and regulatory.

Subsequently, the SMART technique was identified from the literature as a suitable approach to assess the importance (weight) of uncertainty in cloud manufacturing. This technique is one of several weighting methods based on elicitation in a multiple-criteria decision analysis (MCDM) approach that uses experts' or stakeholders' judgment to weight the importance of multiple categories and their alternatives.

The SMART technique was embedded in Microsoft Excel software, and using VBA programming for macros and controls. The advantages of using Microsoft Excel are that it is straightforward to use and manage data, and helpful for presenting results in a visual presentation (charts and graphs).

6.3.2 Simple Multi-Attribute Rating Technique (SMART)

Multiple-criteria decision analysis (MCDA) is a technique in the operations research discipline that has the ability to handle and solve issues involving: multiple factors; a significant amount of information and knowledge; and different alternatives (Jato-Espino *et al.*, 2014).

There are different weighting methods based on elicitation in an MCDM approach that uses experts' or stakeholders' judgment to weight the importance of categories and alternatives (Myllyviita *et al.*, 2014). Some weighting techniques include: SMART, that implements direct entry of relative scores and weights for criteria and alternatives weighting; Swing Technique, that applies a lowest level to highest level range for weighting decision criteria; and Analytic Hierarchy Process (AHP), which employs a ratio scale, pairwise, for comparison of alternatives.

The SMART technique was proposed by Edwards in 1971 (Edwards, 1971), and has become a commonly used tool for decision-makers in the real world (Edwards and Barron, 1994). The advantages of this technique are that: it is a simple tool to implement; its alternatives are independent; it enables the eliciting of numerical judgments; it deals with both qualitative and quantitative criteria; it creates linear form; and it is straight forward to enter the scores and weight. The downside for this technique is the inability to capture all details and complexities of the real problem (Goodwin and Wright, 2014).

The methodology of the SMART technique can be described the in five main steps (Marzouk and Elmesteckawi, 2015), as shown in Figure 6-2:

1. **Identify alternatives:**

   This step can be accomplished by generating a genuine list of uncertainty factors in cloud manufacturing, where each uncertainty has a different impact on cloud manufacturing. As previously mentioned, a list of 32 uncertainty factors has been produced and categorised into three categories: security and privacy category that includes 11 uncertainty factors, a technical category that includes 12 uncertainty factors and management category that includes 9 uncertainty factors.

2. **Identify selection criteria:**

   This step can be accomplished by understanding the organisation's goals, which allow identification of the most important dimensions in cloud manufacturing. The dimensions were identified from literature and interviews with experts in both manufacturing industry and academia. The identified dimensions are security, performance, cost, and regulatory.

3. **Assign relative weights for each criterion:**

   This step can be accomplished by determining weights for each criterion identified in the previous step. The outcome of this step is a rating system for each criterion in cloud manufacturing. First, the decision maker(s) ranks each criterion according to their importance in cloud manufacturing. Then, the decision maker(s) starts to give scores to each criterion based on order of ranking system of the criteria.

4. **Assign weight value for each alternative, on each criterion:**

   This step can be accomplished by assigning a weighted score to each uncertainty factor under each dimension. This step shows the impact of each uncertainty factor under different dimension.

5. **Rank the alternatives according to their weights:**

   This step can be accomplished by multiplying each scaled value of uncertainty factor into their weighted criterion, and then sum all scores for each uncertainty factor. The outcome of this step is a ranking system for each uncertainty factor in cloud manufacturing.

Figure 6-2: SMART technique (Marzouk and Elmesteckawi, 2015)

6.3.3 Data Preparation

The data collection for both alternatives (uncertainties) and criteria (dimensions) were collected previously during the development of uncertainty factors list. The required information for SMART technique implementation was collected through interviews and questionnaires. There were 32 alternatives based on the uncertainty factors list (Section 5.3.5). In addition, four dimensions have been identified based on interviews and interactions with industry. The four dimensions are security, performance, cost, and regulatory. The description of dimensions is as follows:

- **Security:**
  The security in cloud manufacturing refers to providing protection to data, software application, and hardware infrastructure regarding confidentiality, integrity, and availability. This protection can be tangible, such as a set of control-based technologies, or intangible such as policies and rules.
- **Performance:**
  The performance in cloud manufacturing refers to how well the activities and services fulfill their goals in the cloud manufacturing. The limitations within cloud manufacturing can be a major obstacle in cloud manufacturing performance.
- **Cost:**
  The cost in cloud manufacturing refers to all expenses regarding building or using cloud manufacturing, and adding more resources in the cloud. The cost plays an important role when using cloud manufacturing as it can be unexpected or expensive.
- **Regulatory:**
  The regulatory in cloud manufacturing refers to laws and regulations that regulate cloud manufacturing. The majority of laws and regulations are concerned with data location that may cause conflict with regulations and laws of countries that own the data. Also, laws and regulations are responsible for clarifying responsibilities and duties of stakeholders in cloud manufacturing.

6.3.4 Prioritisation Process

Uncertainty importance can be interpreted as to how this uncertainty might affect cloud manufacturing in different dimensions. Measuring the importance of uncertainty can be an arduous step in the uncertainty assessment process because of the nature of the uncertainty. To determine the importance (weight) of uncertainty in cloud manufacturing, a MCDA approach was adopted in this research. This approach is a structured framework that provides advanced calculation methods for both qualitative and quantitative decision criteria (Myllyviita *et al.*, 2014). MCDA is a term for methods and tools that provide findings to decision makers in a situation where there are several conflicting criteria (Løken, 2007; Zavadskas *et al.*, 2014).

Choosing the SMART technique in this phase is the most appropriate MCDM technique for this research because of the technique's advantages mentioned above. An example of applying SMART method methodology:

1. The decision maker is the expert or tool user.
2. The user selects 10 uncertainties to be analysed: Data Location, Data Loss or Leakage, Applications Security, Bandwidth, Service Availability, Hardware/Machine Availability, Latency, Authentication Mechanism, Training and User Boundary.
3. The identified cloud manufacturing dimensions are Security, Performance, Cost, and Regulatory.
4. The user ranks the dimensions according to their decision (most important) as follows: 1) Security. 2) Performance. 3) Regulatory. 4) Cost.
5. The user rates dimensions as follows: Security = 90, Performance = 80, Regulatory = 50, Cost = 30
6. The weight for each dimension is calculated and normalised it into weights summing to 1 (Figure 6-3).

To determine the Importance of uncertainty, Please do the following steps:

Step 1: Rank the Cloud Manufacturing dimensions according to their importance (1 is most important).

Step2: Rate the dimensions by assigning Weight on 10-100 scale according to their important (10 is less important).

Dimension	Rank	Weight	Normalised Weight
Security	1	90	0.36
Performance	2	80	0.32
Regulatory	3	50	0.20
Cost	4	30	0.12

Figure 6-3: Snapshot of uncertainty dimensions weight

7. Values are assigned for each uncertainty, on each dimension, with every value on a scale from 0-10.
8. The score for each uncertainty is calculated by multiplying each scaled value of uncertainty into their weighted dimension, and then summing all scores for each uncertainty (Figure 6-4).

Step3: To calculate weight average of each uncertainty, input value from 1-10 scale for each uncertainty on each dimension.

Uncertainty Name	Category	Security	Performance	Regulatory	Cost	Total Weight
Data Control	Data Security&Privacy	9	5	9	2	**6.88**
Data Loss or Leakage	Data Security&Privacy	10	7	5	5	**7.44**
Applications Security	Data Security&Privacy	10	8	4	5	**7.56**
Bandwidth	Technical	5	10	5	9	**7.08**
Cloud Service Availability	Technical	3	10	4	8	**6.04**
Hardware Availability	Technical	3	9	4	8	**5.72**
Latency	Technical	3	7	3	5	**4.52**
Authentication Mechanism	Management	9	8	8	7	**8.24**
User Boundary	Management	7	8	8	3	**7.04**
Training	Management	2	6	6	7	**4.68**

Figure 6-4: Snapshot of uncertainty total weights

6.4 Phase 2: Uncertainty Quantification

Over the past years, the implementation of new technologies and complex networks in enterprises has created uncertain outcomes and unpredictable situations, known as "uncertainties". The higher existence of uncertainties in problem leads to less understanding of this problem (Booker and Ross, 2011). Due the nature of uncertainty that comes from gaps in knowledge (Epistemic uncertainty), or results natural variability because of the physical environment (Aleatory uncertainty), it is hard to get rid of uncertainties totally, but being aware of them means they can be dealt with (Li *et al.*, 2013).

Decision makers need to characterise and quantify uncertainties in a systematic process in order to determine the outcomes of a model (system) in the presence of uncertainties; this process known as uncertainty quantification. Uncertainty quantification can be defined as "the process of determining the effect of input uncertainties on response metrics of interest" (Eldred *et al.*, 2011). This approach uses mathematical and computer models to analysis the impact of uncertainty on the outcomes of the model (system). In addition, the current techniques that address uncertainties are struggling to become accurate and objective in results(Schwabe *et al.*, 2015).

The majority of the scholars classified methods of uncertainty quantification into two approaches: probabilistic approaches and non-probabilistic approaches (Li *et al.*, 2013; Soroudi and Amraee, 2013; Simoen *et al.*, 2015). Figure 6-5 illustrates the most widely used methods of probabilistic and non-probabilistic approaches.

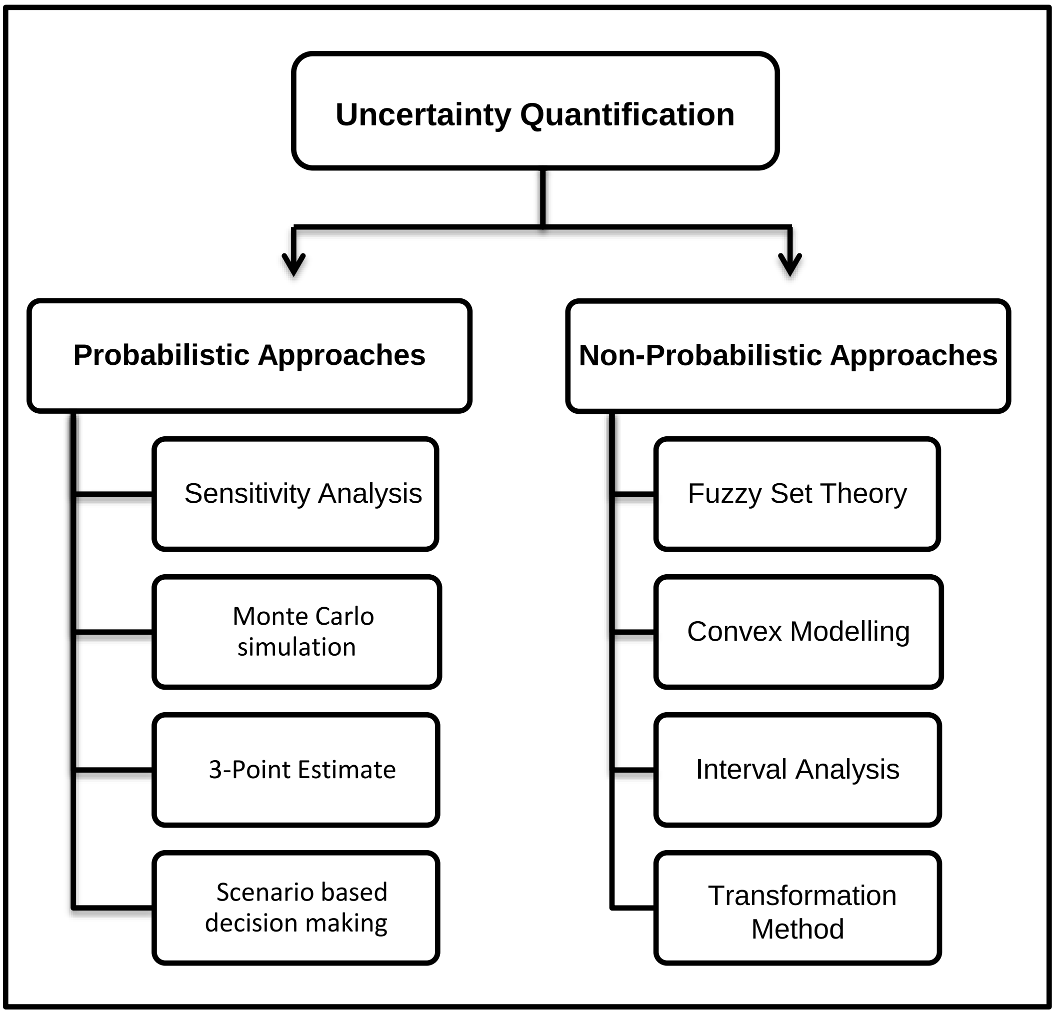


Figure 6-5: Uncertainty quantification methods

The first group of approaches are based on probability theory and use probability density functions (PDFs) to model the uncertainty, while the other group of approaches are based mostly on interval analysis and use a particular value range to present the uncertainty (Simoen *et al.*, 2015).

The probabilistic approaches are suitable for dealing with aleatory uncertainty, where sufficient historical data is available to determine probability density functions (PDFs) for the uncertainties. Non-probabilistic approaches are appropriate to address epistemic uncertainty because of limited data or incomplete knowledge that exist in the uncertainties (Aien *et al.*, 2014).

Cloud manufacturing is considered an emerging technology, with a scarcity of coverage of cloud manufacturing research topics in the literature. This makes it difficult to construct probability density functions for uncertainties that exist in cloud manufacturing. In other words, probabilistic approaches that are based on probability theory cannot apply to uncertainties with knowledge gaps (Aien *et al.*, 2014; Simoen *et al.*, 2015). So, in this research, the author applied non-probabilistic approaches to quantify uncertainties in cloud manufacturing.

In recent years, the increasing attention of scholars on non-probabilistic approaches has grown rapidly. This growth leads non-probabilistic approaches to become a major method to quantify uncertainties. The non-probabilistic approaches include interval analysis, convex modelling, and fuzzy set theory. One of the well-known non-probabilistic approaches is the fuzzy logic approach, which is based on fuzzy set theory.

6.4.1 Fuzzy Logic

Fuzzy logic caught the attention of many scholars in the field of uncertainty quantification because of the ability of fuzzy logic to characterise uncertainty in situations where vague, ambiguous, and imprecise knowledge are present (Darbra *et al.*, 2008; Rodríguez *et al.*, 2016; Yera *et al.*, 2016). Fuzzy logic was introduced by Zadeh in 1965 (Zadeh, 1965), and developed to become a useful tool in both scientific research and commercial fields. It has been applied in a wide variety of research areas, such as: engineering, mathematics, computer software, medical research, social science, business analysis, and the law. It has also been used in numerous other applications, including: facial pattern recognition, air conditioners, washing machines, vacuum cleaners, antiskid braking systems, transmission systems, control of subway systems and unmanned helicopters, knowledge-based systems for multi objective optimization of power systems, weather forecasting systems, models for new product pricing or project risk assessment, medical diagnosis and treatment plans, and stock trading (Singh *et al.*, 2013).

The main advantage of applying a fuzzy logic approach in manufacturing is in its ability to provide a simplified platform. It demonstrates better performance than other approaches in uncertainty quantification. It is more tolerant of imprecision, and allows for the incorporatation of knowledge from experts (Azadegan *et al.*, 2011). There are three main components of fuzzy logic Fuzzification, fuzzy logic inference, and Defuzzification (Sani *et al.*, 2015). Figure 6-6 shows the main components of the fuzzy logic system.

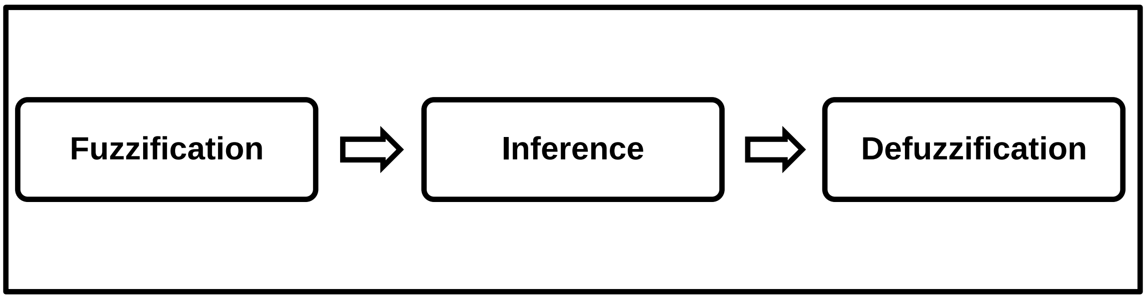


Figure 6-6: Main components of fuzzy logic system

A fuzzy rule-based system (FRBS) is one of the fuzzy logic techniques, and is considered as an important tool to address uncertainty and transform human knowledge (data) into a set of fuzzy IF-THEN rules (information) (Riza *et al.*, 2015). This technique was applied in this research to quantify uncertainties in cloud manufacturing.

6.4.2 Fuzzy Rule Based System Development Methodology

Before representing uncertainties in a fuzzy rule-based system, the three main components of system must first be determined. The initial step is to select relevant input and output variables with their domain. The second step is to define fuzzy sets and construct membership functions for each of the input and output variables. The third step is to formulate fuzzy rules. Next, the mapping is formulated from the input variables to output variables through MATLAB software. Finally, fuzzy results are converted into a crisp output possibility that can be explained and understood. Figure 6-7 illustrates the fuzzy system development methodology.

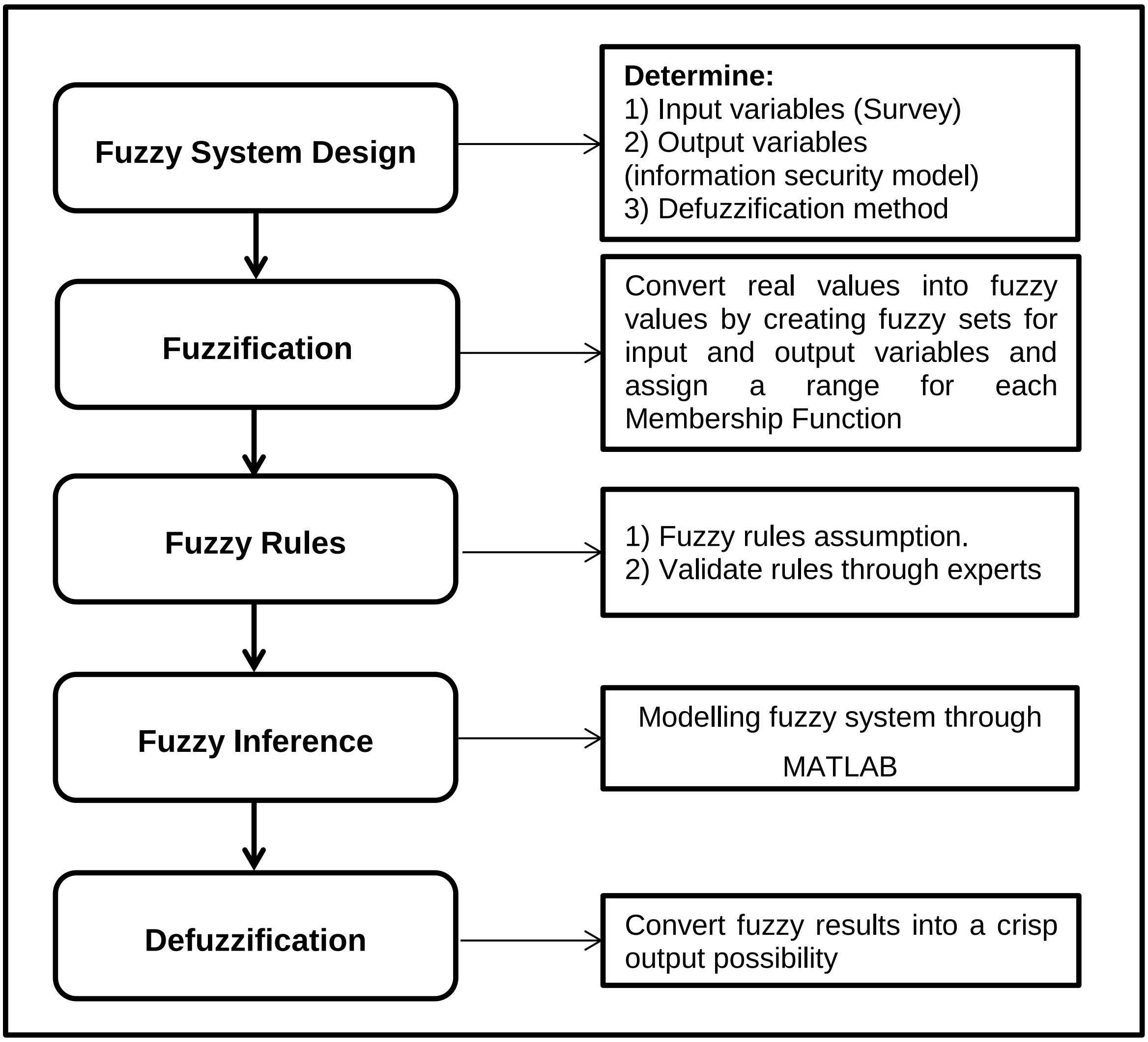


Figure 6-7: Fuzzy System development methodology

6.4.2.1 Fuzzy System Design

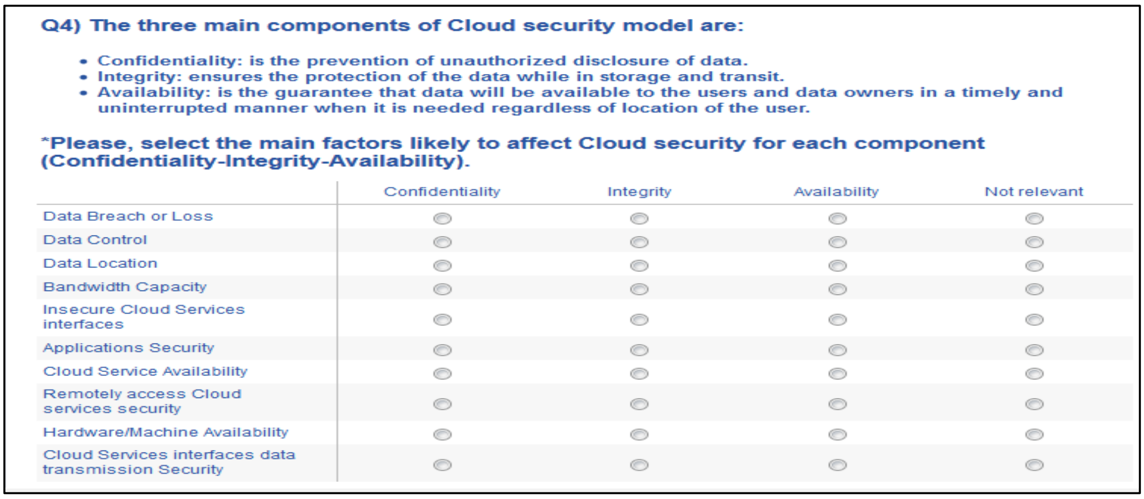
The first step to developing a fuzzy rule-based system is by identifying the input variables and output variables, which requires selecting from numerous uncertainty factors and assigning the right output variables. In this research, the selection of input variables has been performed by means of a questionnaire, and assignment of output variables was by adopting an information security model called “CIA triad”. The C, I, and A stands for Confidentiality, Integrity, and Availability.

6.4.2.1.1 Input variables

There are many uncertainty factors affecting security in cloud manufacturing. The literature and experts' opinion provide an insight into the selection of input variables in the fuzzy system, but the numerous input variables can make for difficulties when generating fuzzy rules. More input variables mean a higher number of rules; it is difficult to extract an answer from those rules.

To minimise the number of input variables, an online questionnaire was developed and distributed to cloud computing technology experts. The aim from the questionnaire was to enable selection of the most important uncertainty factors, according to the CIA model's components (Confidentiality–Integrity–Availability).

The questionnaire was designed with closed questions, based on the finalised uncertainty factor list (section 5.3) and the CIA security model. To validate the content of the questionnaire, a pilot questionnaire was sent to a sample of three individuals (two PhD researchers and one research fellow). The feedback from the pilot questionnaire resulted in adding a definition section to explain the concepts within the questionnaire and rephrase other questions, as shown in Figure 6-8. The finalised questionnaire was structured into three sections with a total of 4 questions: respondents' characteristics (Section 1); definitions and concepts (Section 2); and selecting the most important uncertainty factors in the CIA security model (Section 3).



Q4) The three main components of Cloud security model are:

- Confidentiality: is the prevention of unauthorized disclosure of data.
- Integrity: ensures the protection of the data while in storage and transit.
- Availability: is the guarantee that data will be available to the users and data owners in a timely and uninterrupted manner when it is needed regardless of location of the user.

***Please, select the main factors likely to affect Cloud security for each component (Confidentiality-Integrity-Availability).**

	Confidentiality	Integrity	Availability	Not relevant
Data Breach or Loss				
Data Control				
Data Location				
Bandwidth Capacity				
Insecure Cloud Services interfaces				
Applications Security				
Cloud Service Availability				
Remotely access Cloud services security				
Hardware/Machine Availability				
Cloud Services interfaces data transmission Security				

Figure 6-8: Input variables questionnaire - question 4

The questionnaire was posted on LinkedIn professional cloud computing groups by using Cranfield University's Qualtrics survey tool. Thirty four participants completed the questionnaire. The participants were asked to select the main factors likely to impact cloud security for each component (Confidentiality-Integrity-Availability). Table 6-1 summarises the demographic characteristics of the thirty four participants, showing: industry sector, years of experience, and familiarity with the cloud manufacturing concept.

	Respondents	**Percentage**
Occupation		
Management	7	21%
IT specialist	15	44%
Researcher	11	32%
Other	1	3%
Years of Experience		
1-5 Years	15	45%
6-10 Years	11	33%
11-15 Years	4	12%
16-20 Years	2	6%
21-25 Years	0	0%
More than 25 Years	1	3%
Familiar with Cloud Computing		
Using cloud technology	16	47%
Considers adopting	7	21%
Neither	11	32%

Table 6-1: Demographic characteristics of participants

Findings from the survey results show that among 34 responses, 34 participants selected Data Breach, 25 participants selected cloud Service Interfaces Security, and 27 participants selected Application Security as input variables for the Confidentiality component. For the Integrity component, 31 participants selected Data Control, 24 participants selected Cloud Services Interfaces Data Transmission, and 24 participants selected Remotely Access Cloud Services as input variables. Finally, 33 participants selected Bandwidth Capacity, 34 participants selected Cloud Service Availability, and 30 participants selected Hardware/Machine Availability as input variables for Availability component, as shown in Table 6-2.

Uncertainty Factors	CIA Components			Responses
	Confidentiality	Integrity	Availability	(%)
Data Breach or Loss	34			100%
Data Control		31		91%
Cloud Services Interfaces Data Transmission		24		70%
Bandwidth Capacity			33	97%
Insecure Cloud Services Interfaces	25			73%
Applications Security	27			79%
Cloud Service Availability			34	100%
Remotely Access Cloud Services		24		70%
Hardware/Machine Availability			30	88%

Table 6-2: Participants' responses

6.4.2.1.2 Output variables

In any organisation's information system, including those operating cloud manufacturing, there is a need to protect information security. The information security requirements are to protect the confidentiality, integrity, and availability of the data in cloud manufacturing. Those three characteristics of data are considered the goals to achieve security within cloud manufacturing. A well-known information security model called “CIA triad” (Khansa and Zobel, 2014)was adopted in this research.

CIA Triad is a model for security policy development, used to identify problem areas and necessary solutions for information security. The model contains three components (Khansa and Zobel, 2014; Zafar *et al.*, 2015): Confidentiality, which is the prevention of unauthorised disclosure of information; Integrity, which ensures the protection of the data while in storage and transit; and Availability which is the guarantee that information will be available to the users and data owners in a timely and uninterrupted manner when it is needed regardless of location of the user. Figure 6-9 shows the components of CIA triad.

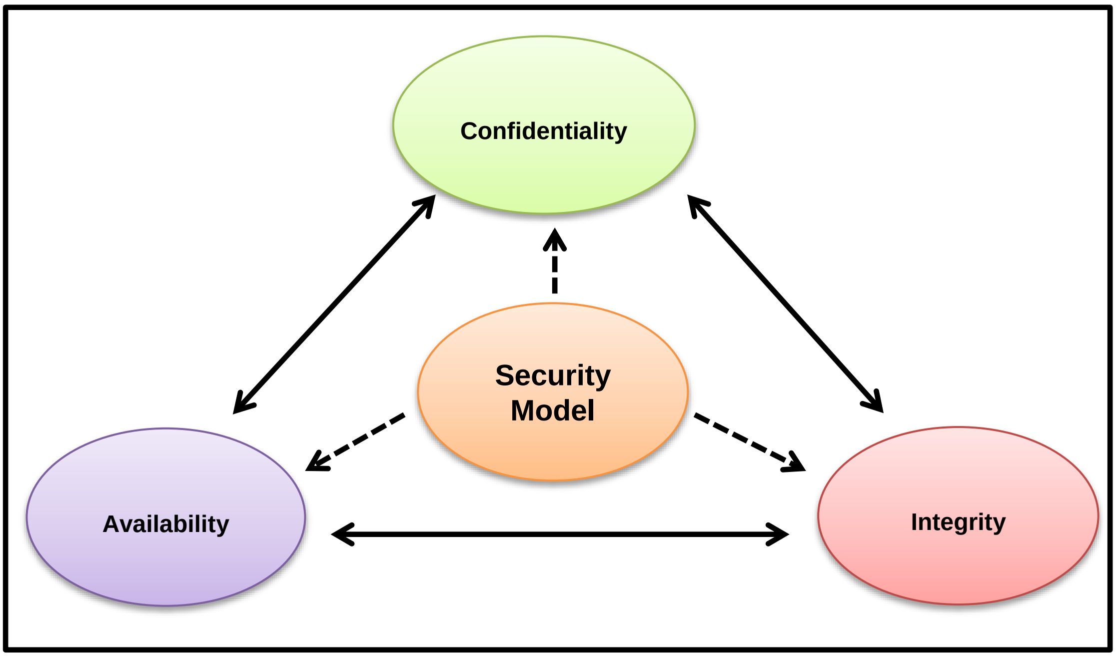


Figure 6-9: CIA triad (Khansa and Zobel, 2014)

The output variables were determined according to the components of the CIA Triad security model. The level of confidentiality is to measure the confidence in cloud manufacturing; the level of integrity is to measure the integrity in cloud manufacturing; and the level of availability is to measure the availability in cloud manufacturing. Note that the input variables (security and privacy uncertainty factors) and output variables (CIA components) have an inverse relationship between them, where an increase in the value of the uncertainty factor results in a decrease in the value of the component of CIA security.

6.4.2.2 Fuzzification

The fuzzy sets were developed based on interviews with five experts in the field of Information Technology who had requisite knowledge of fuzzy logic. For each input and an output variable, the linguistic variables were defined with their numeral intervals, and then represented by constructing the membership function. Tables 6-3 and 6-4 illustrate the fuzzy sets for input and output variables and their values.

Input Variable	**Fuzzy sets values**		
	LOW	**MODERATE**	**HIGH**
Data Breach	0 - 4	2 - 8	6 - 10
Insecure Cloud Services Interfaces			
Applications Security			
Data Control			
Remotely Access Cloud Services			
Cloud Services Interfaces Data Transmission			
Bandwidth Capacity			
Cloud Service Availability			
Hardware/Machine Availability			

Table 6-3: Fuzzy sets for input variables and their values

From the above table, the input variable column represents the input linguistic variable (uncertainty). The fuzzy sets values column represents the linguistic terms (low, moderate, high) with their numerical range. While in the table below, the output variable column represents the output linguistic variables

(CIA's components). The fuzzy sets values column represents the linguistic terms (low, moderate, high) with their numerical range for CIA model's components (Confidentiality – Integrity – Availability).

Output Variable	Fuzzy sets values		
	LOW	MODERATE	HIGH
Confidentiality	0 - 40	20 - 80	60 - 100
Integrity			
Availability			

Table 6-4: Fuzzy sets for output variables and their values

Each fuzzy set has its own membership function. In this research, there are nine input membership functions and three output membership functions. The membership function is considered as a graphical representation of the fuzzy set. Figures 6-10 to 6-21 show the membership function of the input and output variables.

Figure 6-10 illustrates the fuzzy representation of the data breach linguistic variable. The horizontal axis represents the range of all possible values for impact of data breach uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for data breach linguistic variable (low, moderate, high), where the range for linguistic term "low" is between 0 and 4, the range for linguistic term "moderate" is between 2 and 8, and range for linguistic term "high" is between 6 and 10.

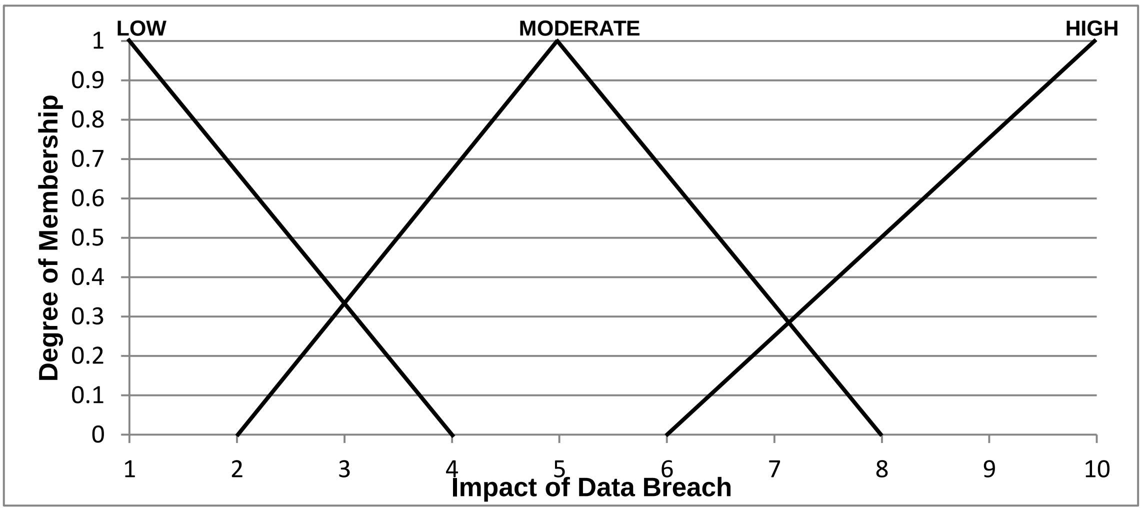


Figure 6-10: Membership function for Data Breach

Figure 6-11 illustrates the fuzzy representation of the insecure cloud services interfaces linguistic variable. The horizontal axis represents the range of all possible values for impact of insecure cloud services interfaces uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for insecure cloud services interfaces linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 4, the range for linguistic term “moderate” is between 2 and 8, and range for linguistic term “high” is between 6 and 10.

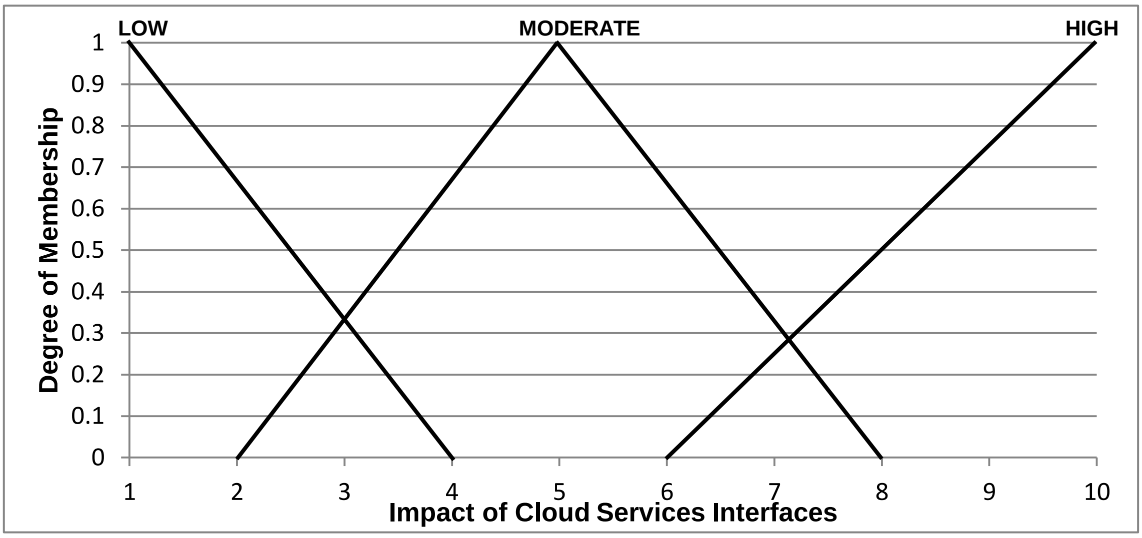


Figure 6-11: Membership function for Cloud Service Interface Security

Figure 6-12 illustrates the fuzzy representation of the applications security linguistic variable. The horizontal axis represents the range of all possible values for impact of applications security uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for applications security linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 4, the range for linguistic term “moderate” is between 2 and 8, and range for linguistic term “high” is between 6 and 10.

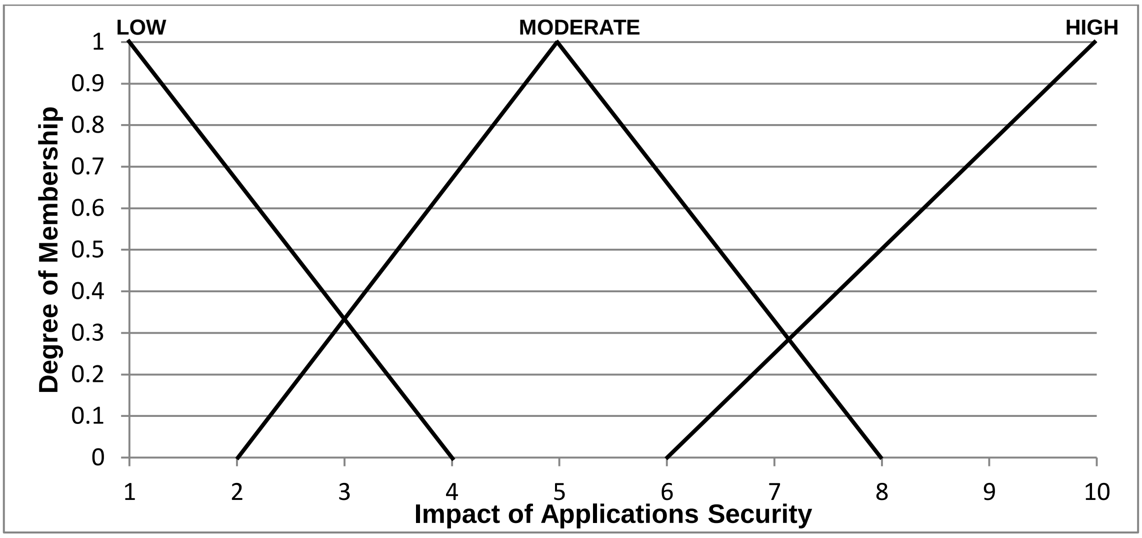


Figure 6-12: Membership function for Applications Security

Figure 6-13 illustrates the fuzzy representation of the data control linguistic variable. The horizontal axis represents the range of all possible values for impact of data control uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for data control linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 4, the range for linguistic term “moderate” is between 2 and 8, and range for linguistic term “high” is between 6 and 10.

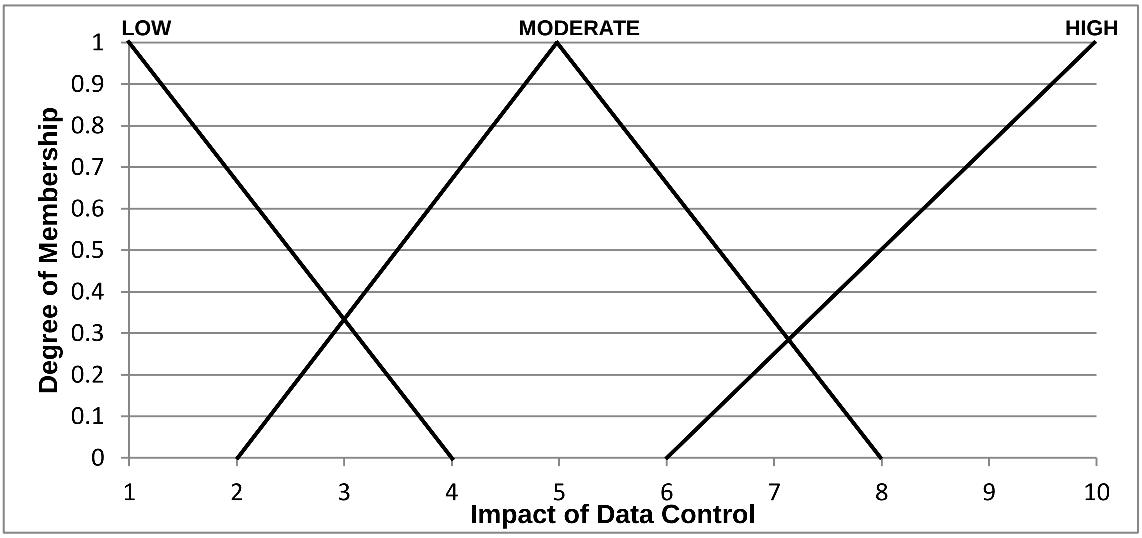


Figure 6-13: Membership function for Data Control

Figure 6-14 illustrates the fuzzy representation of the remotely access cloud services linguistic variable. The horizontal axis represents the range of all possible values for impact of remotely access cloud services uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for remotely access cloud services linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 4, the range for linguistic term “moderate” is between 2 and 8, and range for linguistic term “high” is between 6 and 10.

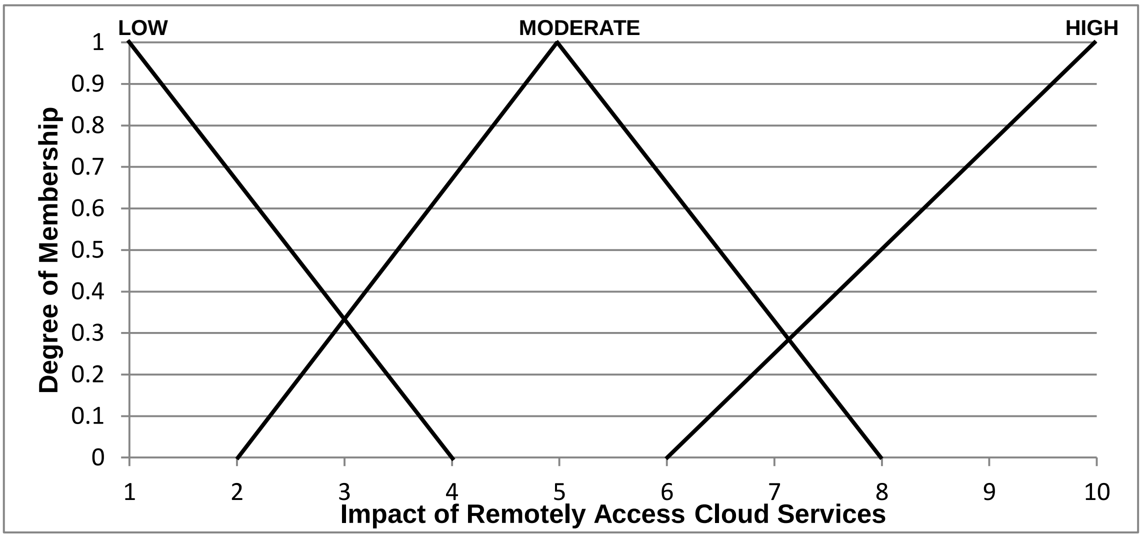


Figure 6-14: Membership function for Remotely Access Cloud Services

Figure 6-15 illustrates the fuzzy representation of the cloud services interfaces data transmission linguistic variable. The horizontal axis represents the range of all possible values for impact of cloud services interfaces data transmission uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for cloud services interfaces data transmission linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 4, the range for linguistic term “moderate” is between 2 and 8, and range for linguistic term “high” is between 6 and 10.

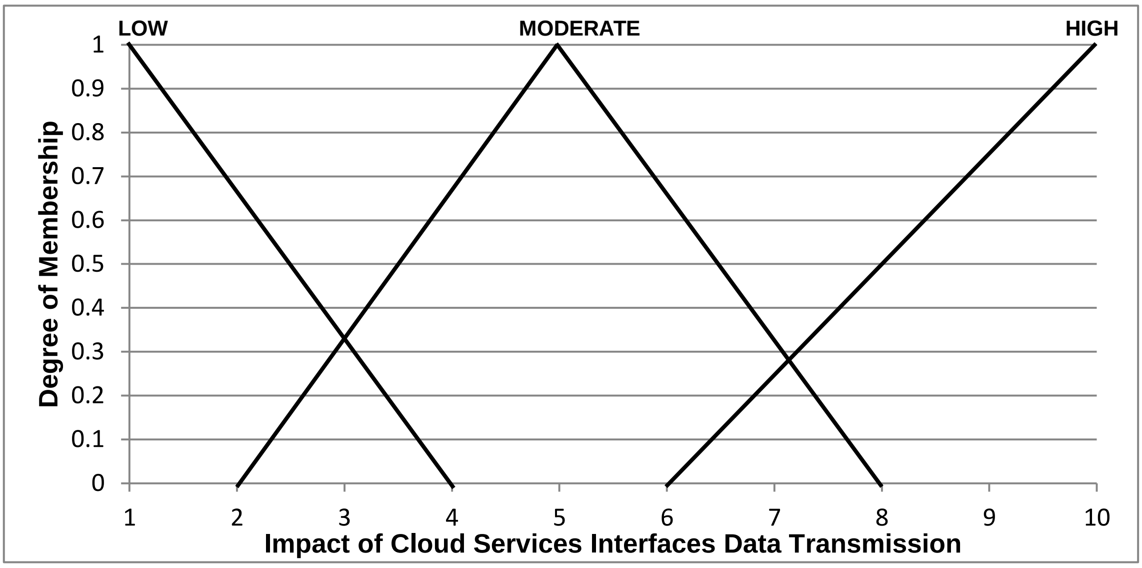


Figure 6-15: Membership function for Cloud Interfaces Data Transmission

Figure 6-16 illustrates the fuzzy representation of the bandwidth capacity linguistic variable. The horizontal axis represents the range of all possible values for impact of bandwidth capacity uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for bandwidth capacity linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 4, the range for linguistic term “moderate” is between 2 and 8, and range for linguistic term “high” is between 6 and 10.

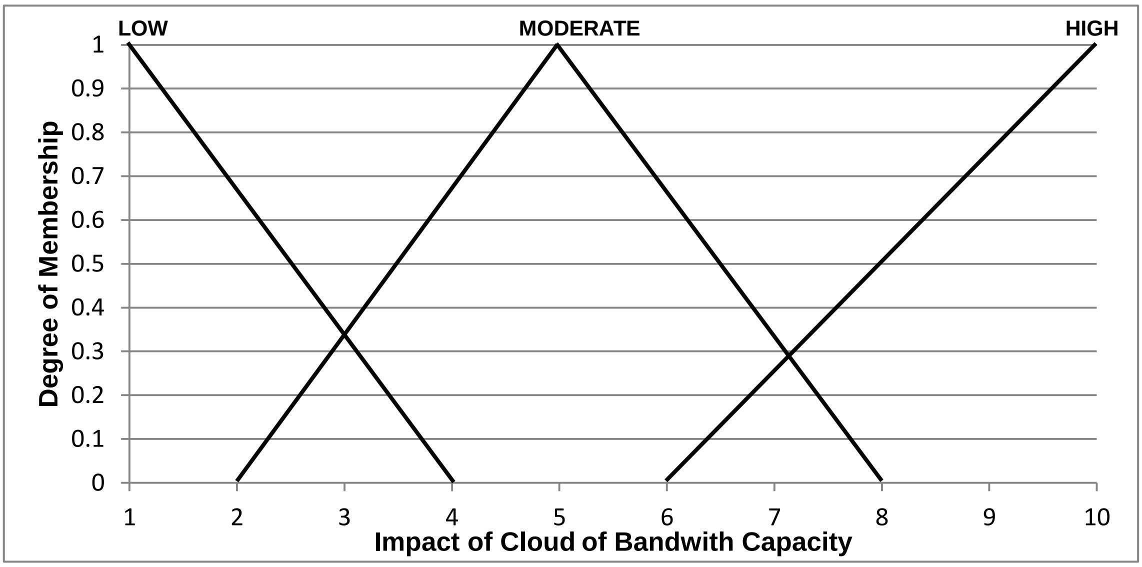


Figure 6-16: Membership function for Bandwidth Capacity

Figure 6-17 illustrates the fuzzy representation of the cloud service availability linguistic variable. The horizontal axis represents the range of all possible values for impact of cloud service availability uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for cloud service availability linguistic variable (low, moderate, high), where the range for linguistic term "low" is between 0 and 4, the range for linguistic term "moderate" is between 2 and 8, and range for linguistic term "high" is between 6 and 10.

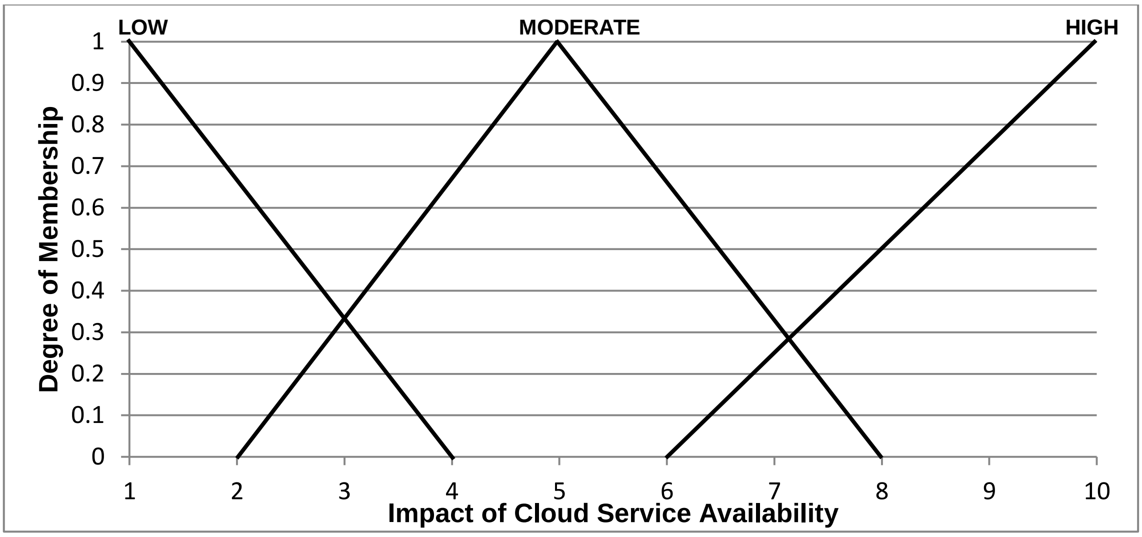


Figure 6-17: Membership function for Cloud Service Availability

Figure 6-18 illustrates the fuzzy representation of the hardware/machine availability linguistic variable. The horizontal axis represents the range of all possible values for impact of hardware/machine availability uncertainty factor in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for hardware/machine availability linguistic variable (low, moderate, high), where the range for linguistic term "low" is between 0 and 4, the range for linguistic term "moderate" is between 2 and 8, and range for linguistic term "high" is between 6 and 10.

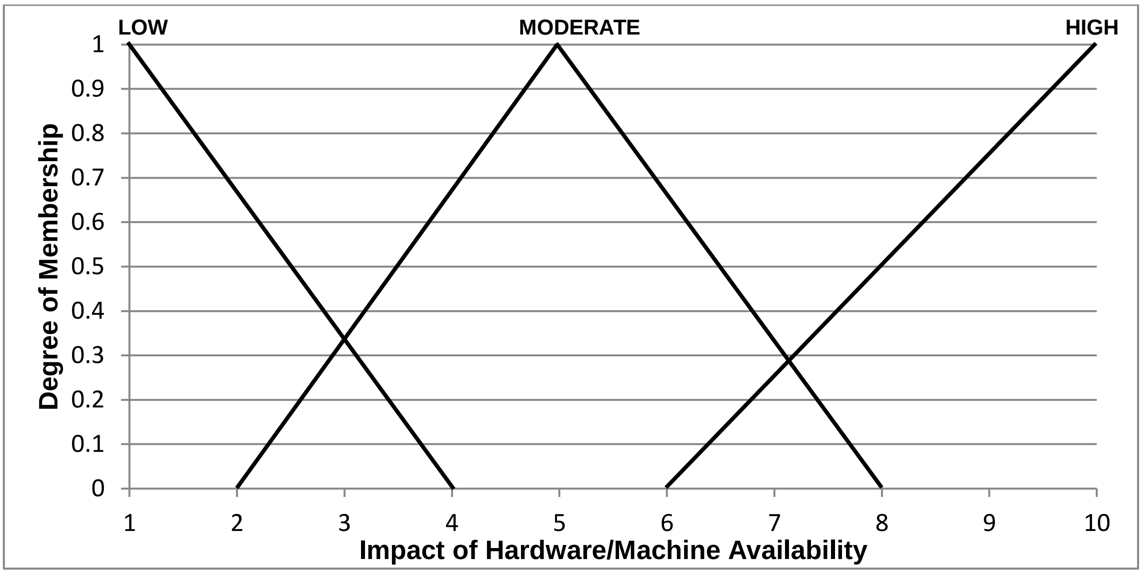


Figure 6-18: Membership function for Hardware/Machine Availability

Figure 6-19 illustrates the fuzzy representation of the level of confidentiality linguistic variable. The horizontal axis represents the range of all possible values for level of confidentiality in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for level of confidentiality linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 40, the range for linguistic term “moderate” is between 20 and 80, and range for linguistic term “high” is between 60 and 100.

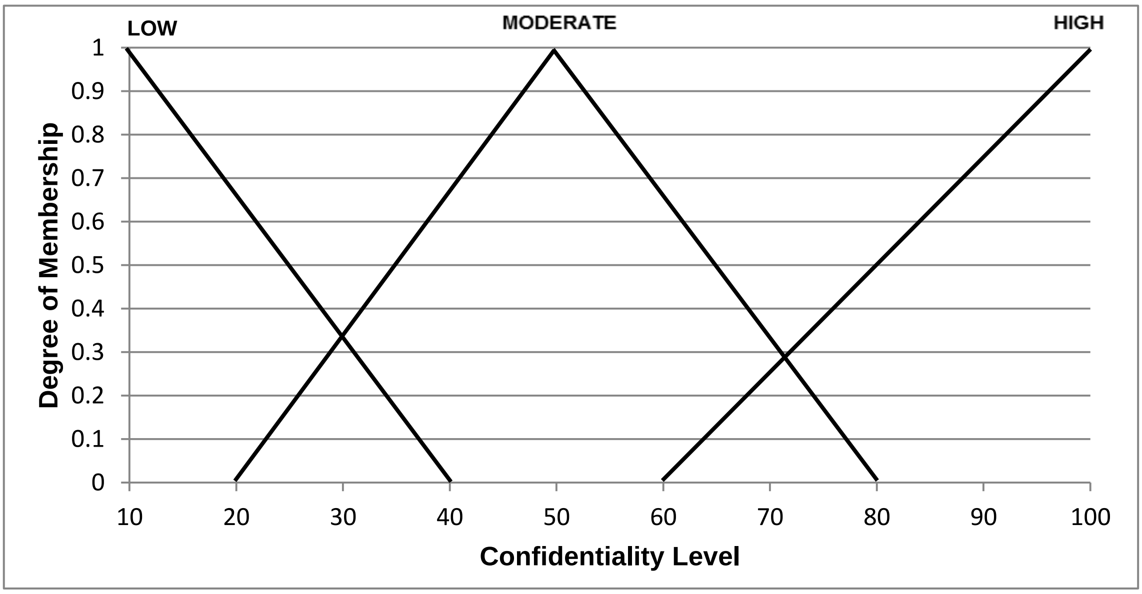


Figure 6-19: Membership function for Level of Confidentiality

Figure 6-20 illustrates the fuzzy representation of level of the integrity linguistic variable. The horizontal axis represents the range of all possible values for level of integrity in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for level of integrity linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 40, the range for linguistic term “moderate” is between 20 and 80, and range for linguistic term “high” is between 60 and 100.

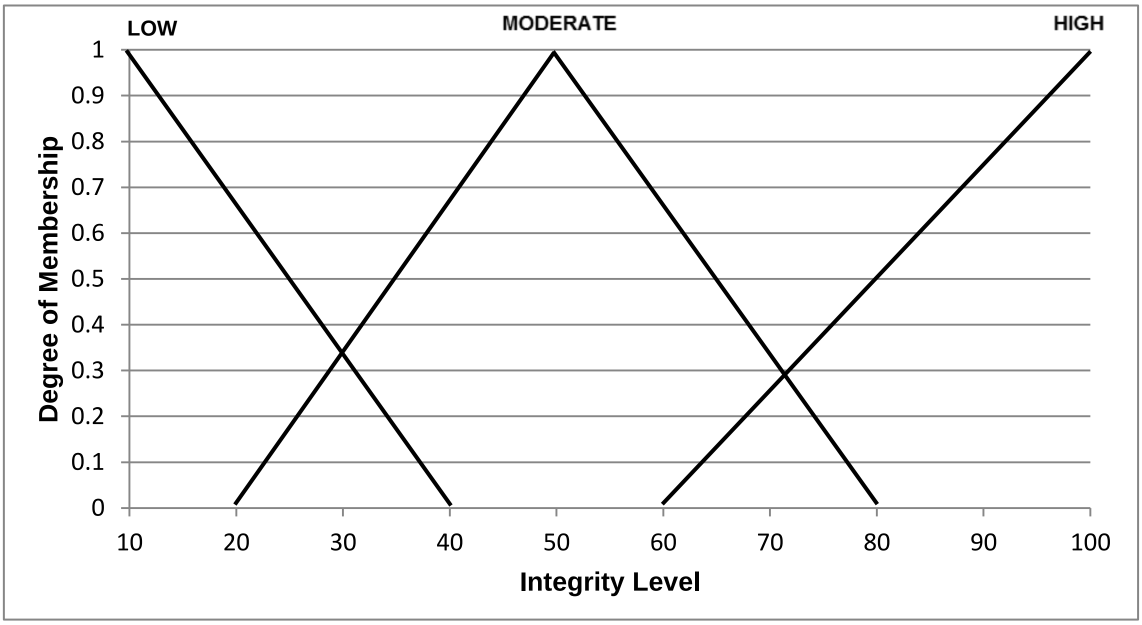


Figure 6-20: Membership function for Level of Integrity

Figure 6-21 illustrates the fuzzy representation of the level of availability linguistic variable. The horizontal axis represents the range of all possible values for level of availability in cloud manufacturing. While the vertical axis represents the degree of membership value. The membership function includes all linguistic terms for level of availability linguistic variable (low, moderate, high), where the range for linguistic term “low” is between 0 and 40, the range for linguistic term “moderate” is between 20 and 80, and range for linguistic term “high” is between 60 and 100.

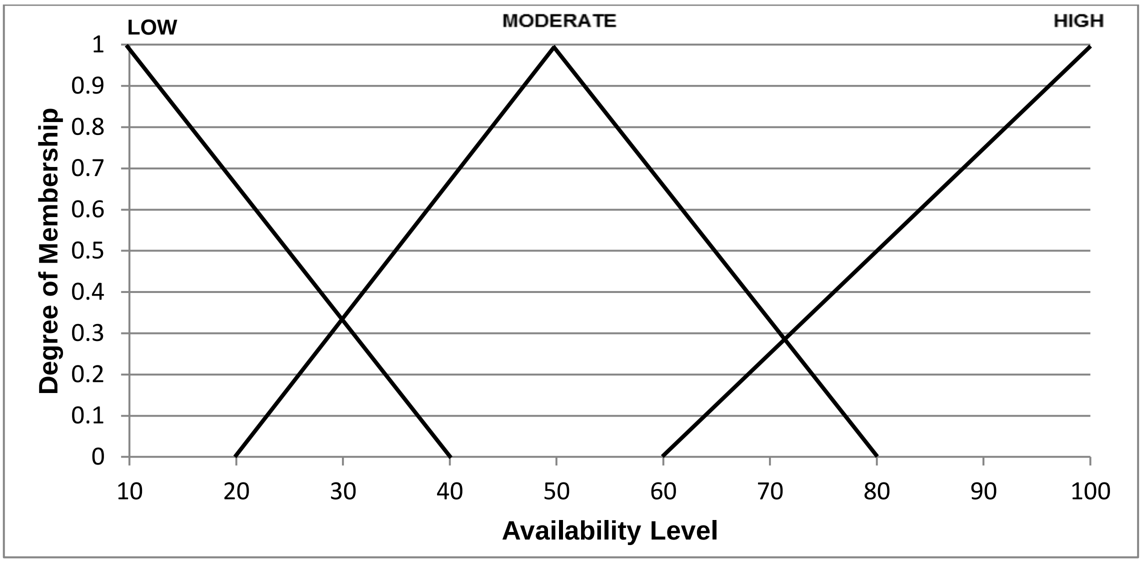


Figure 6-21: Membership function for Level of Availability

6.4.2.3 Fuzzy Rules

The next step to building a fuzzy system is to formulate fuzzy rules. The construction of fuzzy rules began with determining the input variables and output variables, then interviewing two Information Technology experts to extract the rules. Finally, 81 fuzzy rules for fuzzy rule-based system have been formulated. Figure 6-22 shows a sample of fuzzy rules. (See Appendix D for fuzzy rules in detail).

1) IF (Data Breach = LOW) AND (Cloud Service Interfaces = LOW) AND (Applications Security = LOW) THEN(Confidentiality = LOW)
2) IF (Data Breach = LOW) AND (Cloud Service Interfaces = LOW) AND (Applications Security = MODERATE) THEN(Confidentiality = LOW)
3) IF (Data Breach = LOW) AND (Cloud Service Interfaces = LOW) AND (Applications Security = HIGH) THEN(Confidentiality = MODERATE)
4) IF (Data Breach = LOW) AND (Cloud Service Interfaces = MODERATE) AND (Applications Security = LOW) THEN(Confidentiality = LOW)
5) IF (Data Breach = LOW) AND (Cloud Service Interfaces = MODERATE) AND (Applications Security = MODERATE) THEN(Confidentiality = LOW)
6) IF (Data Breach = LOW) AND (Cloud Service Interfaces = MODERATE) AND (Applications Security = HIGH) THEN(Confidentiality = MODERATE)
7) IF (Data Breach = LOW) AND (Cloud Service Interfaces = HIGH) AND (Applications Security = LOW) THEN(Confidentiality = MODERATE)
8) IF (Data Breach = LOW) AND (Cloud Service Interfaces = HIGH) AND (Applications Security = MODERATE) THEN(Confidentiality = MODERATE)
9) IF (Data Breach = LOW) AND (Cloud Service Interfaces = HIGH) AND (Applications Security = HIGH) THEN(Confidentiality = HIGH)
10) IF (Data Breach = MODERATE) AND (Cloud Service Interfaces = LOW) AND (Applications Security = LOW) THEN(Confidentiality = LOW)

Figure 6-22: Sample of fuzzy rules

Fuzzy rules may be expressed in terms such as “IF input variable is X THEN Output variable is Y”. Some examples to explain fuzzy rules:

> IF *data breach* is **MODERATE** and *cloud service interfaces* is **HIGH** and *applications security* is **HIGH**, then *Confidentiality* is **HIGH**

Fuzzy rules determine what action to execute according to the condition of the input variables. The data breach uncertainty factor is moderate which means the security measurements to prevent a data breach is inefficient at moderate level, and its impact is moderate on the level of confidentiality in the cloud. The cloud service interfaces uncertainty factor is high which means the cloud services interfaces are unsecure at high level, and its impact is high on the level of confidentiality in the cloud. The application security is high which means the security measurement to protect the application is inefficient at high level, and its impact is high on the level of confidentiality in the cloud. The decision that obtains from applying the fuzzy rule which indicates that the impact of confidentiality's uncertainty factors is high, which results in low level of confidentiality in cloud manufacturing security.

> IF *Data Control* is **HIGH** AND *Remotely Access Cloud Services* is **LOW** AND *Cloud services interfaces data transmission* is **MODERATE** THEN Integrity is **MODERATE**

The data control is high which means the degree of controlling the data in the cloud is inefficient at high level, and its impact is high on the level of integrity in the cloud. The remotely access cloud services is low which means the remote access cloud services that may effect encryption/ decryption mechanism in the cloud is low, and its impact is low on the level of integrity in the cloud. The cloud services interface data transmission is moderate which means the security measurements for transmission between cloud services interfaces is inefficient at moderate level, and its impact is moderate on the level of integrity in the cloud. The decision that obtains from applying the fuzzy rule indicates that the impact of integrity's uncertainty factors is moderate, which results in moderate level of integrity in cloud manufacturing security.

IF *Bandwidth Capacity* is **HIGH** AND *Cloud Service Availability* is **MODERATE** AND *Machine Availability* is **HIGH** THEN Availability is **HIGH**

The Bandwidth capacity is high which means the ability of bandwidth capacity to handle and collect real time data from cloud manufacturing is inefficient at high level, and its impact is high on the level of availability in the cloud. The cloud service availability is moderate which means the ability to prevent network outage and system failures of cloud service is moderate, and its impact is moderate on the level of availability in the cloud. The hardware/machine availability is high which means the ability to access and connect the hardware/machines is inefficient at high level, and its impact is high on the level of availability in the cloud. The decision that obtains from applying the fuzzy rule which indicates that the impact of availability's uncertainty factors is high, which results in low level of availability in cloud manufacturing security.

6.4.2.4 Fuzzy Inference

The main components of the developed fuzzy system were determined, which were identifying the input variables and output variables, creating the fuzzy sets and membership functions, and formulating fuzzy rules. The next important step is to map all of the previous steps into the fuzzy system by using the software program, MATLAB.

The process of mapping the input variables to output variables by using the fuzzy logic concept is called fuzzy inference system (FIS). There are a number of recognised methods for fuzzy inference. The most two important methods are Mamdani and Sugeno fuzzy inference systems. In the research, Mamdani’s fuzzy inference method was applied to qualify uncertainties. The main difference between Mamdani's fuzzy inference method and Sugeno fuzzy inference method is the fuzzy rule expression. In Mamdani's fuzzy inference, the fuzzy rule is expressed in linguistic form, while in Sugeno’s fuzzy inference the fuzzy rule is expressed mathematically in terms of the input variables (Jayawardena *et al.*, 2014). The Mamdani's fuzzy inference method was proposed by Mamdani and Assilian in 1975 (Mamdani and Assilian, 1975) to control a steam engine and boiler combination by applying fuzzy logic. It has become a commonly used methodology to apply fuzzy inference system in many applications in the real world.

The Mamdani fuzzy inference system begins by specifying the number of input and output variables: there are nine input variables and three output variables. After that, a set of fuzzy rules are determined, where the crisp input variables are transformed into fuzzy sets. Next, the fuzzy input variables are applied into the fuzzy rules. The fuzzified inputs are applied to fuzzy rule antecedents by using fuzzy operations to receive the result of the antecedent evaluation. Then, the results of the antecedent evaluation and output membership function are combined to find the consequence of the rule. Next, all fuzzy rule consequents are combined to deliver a single fuzzy set. Finally, the aggregate output fuzzy set is defuzzified to obtain a crisp number. Figure 6-23 shows the fuzzy inference system (FIS).

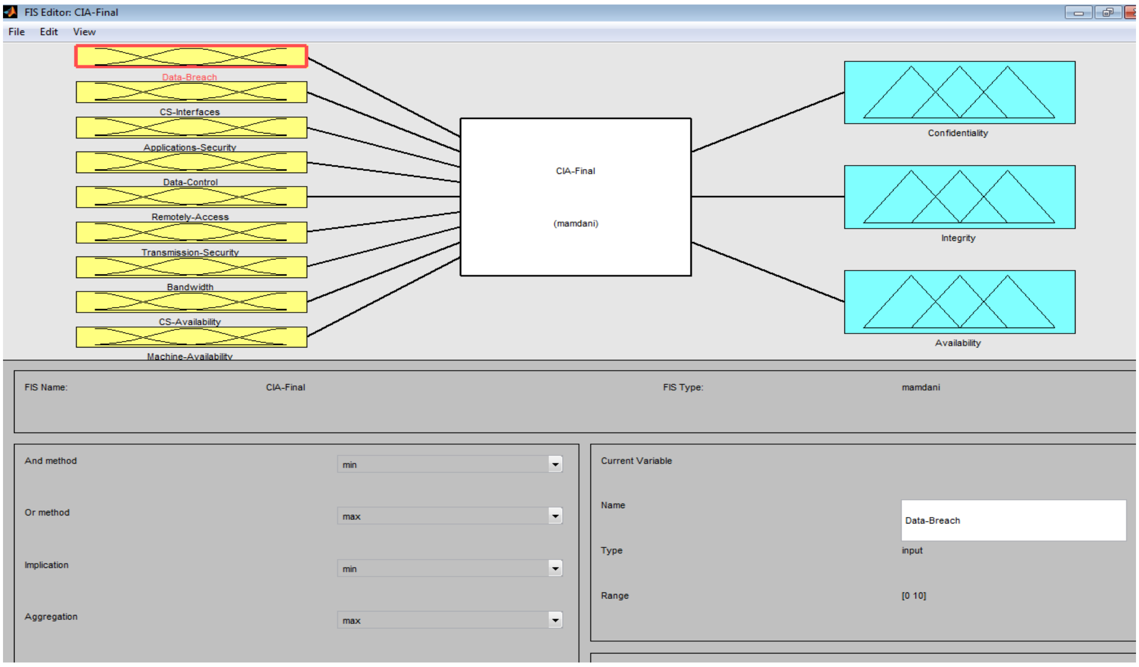


Figure 6-23: FIS editor

Surface viewer represents the relationship between input variables and output variable graphically. This 3-D plot enables an understanding of how the fuzzy inference system was dsigned by graphically illustrating the mapping between any inputs and any output in the system. Figure 6-24 demonstrates the surface viewer with three-dimensional plots for two input variables (Bandwidth and Hardware/Machine Availability) and one output variable (level of availability). The Z- axis represents the level of availability in cloud manufacturing. While the x-axis and y-axis represent Bandwidth and Hardware/Machine Availability. The 3-D plot shows all possible range values for Bandwidth and Hardware/Machine Availability against the possible range values for the level of availability.

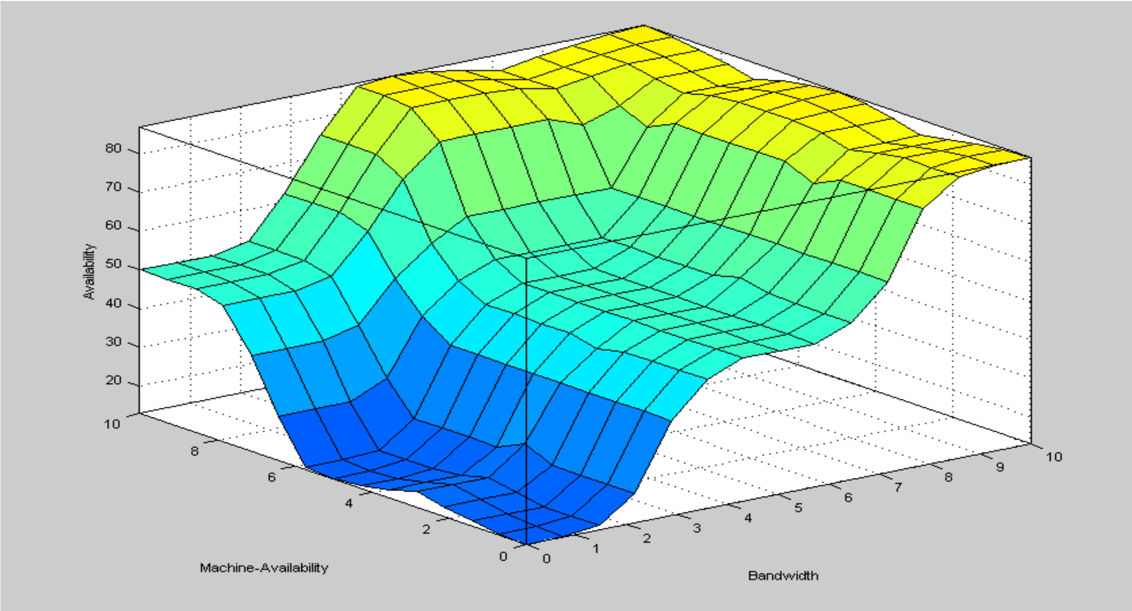


Figure 6-24: Surface viewer

6.4.2.5 Defuzzification

The final step in Mamdani's fuzzy inference system is Defuzzification. Defuzzification can be defined as a process to obtain quantifiable crisp values from the fuzzy sets and corresponding membership degrees (Sani *et al.*, 2015). In other words, Defuzzification is the reverse process of Fuzzification, where the aggregate output fuzzy set (fuzzy number) is the input for the Defuzzification process to obtain a crisp number (Negnevitsky, 2011).

There are various methods for Defuzzification, such as Centre of Gravity (COG), Bisector of area (BOA), last of maximum (LOM), mean of maxima (MeOM), and middle of maximum (MOM), but the Centre of Gravity method remains one of the most widespread methods of Defuzzification (Negnevitsky, 2011; Roy *et al.*, 2016). Also, the Centre of Gravity method can provide high accuracy calculations in fuzzy inference systems (Cheng and Lu, 2015). Centre of Gravity (COG) was adopted in this research as the Defuzzification method in the fuzzy inference system.

The Centre of Gravity method computes the centre of gravity for the area under the curve of the aggregated output fuzzy set, as illustrated in Figure 6-25. It begins by identifying the point of the centre of gravity of the fuzzy set and divides the aggregate set into two areas of equally mass by a vertical line (Negnevitsky, 2011). The Centre of Gravity method is expressed mathematically as:

$$COG = \frac{\sum_{x=a}^{b} u_A(x)x}{\sum_{x=a}^{b} u_A(x)}$$

Where: COG = number of counts to be used for the output

$u_A(x)$ = range of the linguistic variable (membership function)

x = value of the linguistic variable

a, b = number of output members

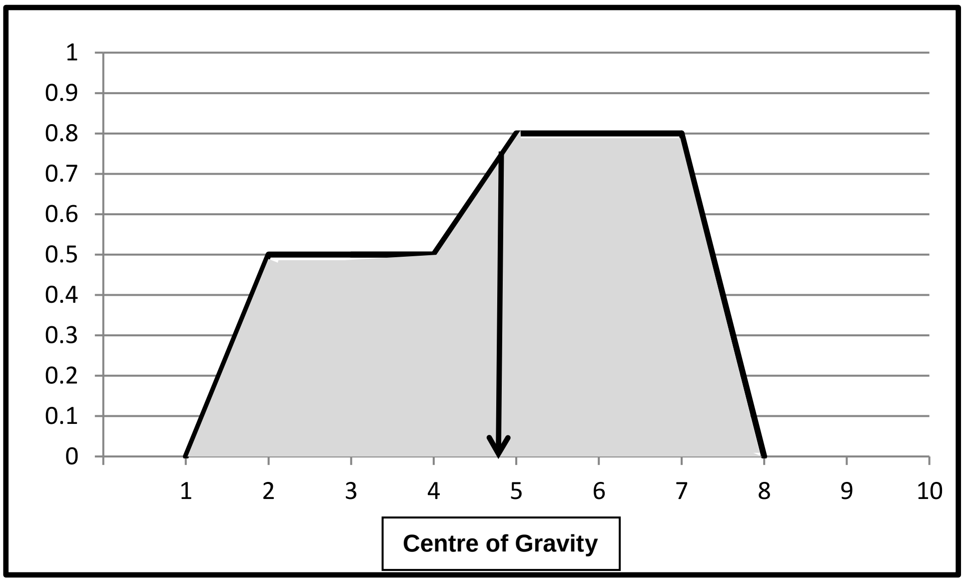


Figure 6-25: Centre of gravity method

6.5 Knowledge Base

The second part of uncertainty quantification is to construct a knowledge base for security and privacy uncertainty factors in terms of confidentiality, integrity, and availability in cloud manufacturing. The aim of this knowledge base is to enhance the decision-making process in organisations that are considering adopting cloud manufacturing. The knowledge base transforms data into valuable and high-quality knowledge through providing recommendations and solutions to control and deal with security and privacy uncertainty factors in cloud manufacturing. To ensure constructing a successful knowledge base, the knowledge acquisition must be highly accurate and include precise knowledge from various sources. The sources of knowledge base were based on experts in Information Technology and manufacturing industries, literature, books, and standards.

The knowledge base is composed of two bases: classification base and recommendation base. The classification base is used to classify the CIA model's components (Confidentiality – Integrity – Availability). While in the recommendation base, decision rules are provided that deliver strategies for decision makers for moving to the cloud and recommendations are made on how to deal with security and privacy uncertainty factors. Both bases complement each other in the sense that can provide a better understanding of security and privacy uncertainty factors in cloud manufacturing.

6.5.1 Classification Base

The knowledge acquisition for the classification base was based on NIST's standard, named FIPS-199, published in 2004 (NIST, 2004). FIPS-199 (Federal Information Processing Standard Publication 199, Standards for Security Categorisation of Federal Information and Information Systems) is a United States Federal Government standard issued by the National Institute of Standards and Technology (NIST). This standard establishes security categories of information systems used by the Federal Government, one component of risk assessment. FIPS 199, along with FIPS 200, are mandatory security standards as required by FISMA. FIPS 199 requires Federal agencies to assess their information systems in each of the categories of confidentiality, integrity and availability, rating each system as low, moderate or high impact in each category. The most severe rating from any category becomes the information system's overall security categorisation.

The knowledge obtained from FIPS-199 standard enabled the classification base to rate the security model components (confidentiality, integrity and availability) in cloud manufacturing, where each compound was rated in terms of low, moderate and high, based on its impact on security in cloud manufacturing. Also, a full description was provided for each security model component that defines three levels of impact (low, moderate or high). Table 6-5 shows the impact definitions for each security model component.

After Mamdani's fuzzy inference system quantifies the security and privacy uncertainty factors, the classification base begins to assign each component of the security model with the impact value (low, moderate or high) for security in cloud manufacturing. This step allows decision makers to understand the impact of uncertainty factors in terms of the level of confidentiality, the level of integrity, and level of availability.

6.5.2 Recommendation Base

A set of structured interviews with five professionals was conducted to acquire knowledge from their expertise. The results from those interviews were used to establish a recommendation base that contains recommendations and solutions to deal with and control security and privacy uncertainty factors in cloud manufacturing. The five experts had a mix of experience (ranging from 16 to 27 years), and backgrounds in Information Technology, manufacturing, and cloud technology. Table 6-6 shows the details of five experts

Security model component	Impact		
	Low	**Moderate**	**High**
Confidentiality	The unauthorized disclosure of information could be expected to have a limited adverse effect on organisational operations, organisational assets, or individuals.	The unauthorized disclosure of information could be expected to have a serious adverse effect on organisational operations, organisational assets, or individuals.	The unauthorized disclosure of information could be expected to have a severe or catastrophic adverse effect on organisational operations, organisational assets, or individuals.
Integrity	The unauthorized modification or destruction of information could be expected to have a limited adverse effect on organizational operations, organisational assets, or individuals.	The unauthorized modification or destruction of information could be expected to have a serious adverse effect on organizational operations, organisational assets, or individuals	The unauthorized modification or destruction of information could be expected to have a severe or catastrophic adverse effect on organisational operations, organisational assets, or individuals.
Availability	The disruption of access to or use of information or an information system could be expected to have a limited adverse effect on organizational operations, organisational assets, or individuals.	The disruption of access to or use of information or an information system could be expected to have a serious adverse effect on organizational operations, organisational assets, or individuals.	The disruption of access to or use of information or an information system could be expected to have a severe or catastrophic adverse effect on organizational operations, organisational assets, or individuals.

Table 6-5: Impact definitions for each security model component (FIPS-199 standard)

.

No	Expert	Organisation	Role	Experience
1	Software Engineering	Manufacturing Services Company	Senior Software Engineer	27 Years
2	Network Engineering	Government Organisation	Head of Section	16 Years
3	Computer Engineering	Telecommunication Company	Project Manager	16 Years
4	Computer Engineering	IT Management Service Company	Manager	16 Years
5	Network Engineering	Web Hosting Service Company	Manager	18 Years

Table 6-6: Experts experience

The knowledge acquired from the interviews was used to construct the decision rules. The decision rules were expressed as a form of IF-THEN statements. Each decision rule in the recommendation base represents a strategy and solution on how to deal with uncertainty factors. A decision rule comprises of two parts: the antecedent - IF part - consists of conditions, while the consequent - THEN part - consists of actions. The conditions are crisp outcomes from Mamdani's fuzzy inference system, and the actions are the strategies and solutions for handling cloud manufacturing and its uncertainties.

The knowledge base consists of five decision-making strategies that provide advice and solutions to decision makers regarding cloud manufacturing. The five decision-making strategies were represented in the form of IF-THEN statements. The explanation of each type of strategy is as follows:

(1) Deploy To Cloud:

In this strategy, the recommendation is to move to cloud manufacturing. This recommendation is based on the level of security in the cloud. The impact of uncertainty factors on confidentiality, integrity, and availability are very low on security in the cloud. The security measurements in this situation are very safe and suitable for organisations that are using or considering adopting cloud manufacturing.

(2) Deploy To Cloud with Minor Recommendations:

In this strategy, the recommendation is to move to cloud manufacturing with minor recommendations. This recommendation is based on the level of security in the cloud. The impact of uncertainty factors on confidentiality, integrity, and availability are between low to moderate on security in the cloud. The security measures in this situation need to be enhanced and have new resources added. The recommendations for this strategy are: upgrade software and hardware protection (firewalls), control user access to the cloud, maintain access rules, backup cloud data, monitor data access (log files), update (antivirus) software protection, upgrade network resources, and add redundancy.

(3) Deploy To Cloud with Moderate Recommendations:

In this strategy, the recommendation is to move to cloud manufacturing with moderate recommendations. This recommendation is based on the level of security in the cloud. The impact of the uncertainty factors on confidentiality, integrity and availability on security in the cloud vary from low to moderate to high on security in the cloud. The security measurements in this situation need to upgrade the existing security measurements and add new resources for security. The recommendations for this strategy are: provide access control (create rules), upgrade software and hardware protection (firewalls), control user access into the cloud, maintenance access rules, backup cloud data, add software protection (antivirus), create permissions rules, monitor data access, add more network resources, add redundancy, and increase bandwidth capacity.

(4) Deploy To Cloud with Major Recommendations:

In this strategy, the recommendation is to move to cloud manufacturing with major recommendations. This recommendation is based on the level of security in the cloud. The impact of uncertainty factors on confidentiality, integrity, and availability are between moderate to high on security in the cloud. The security measures in this situation need to be fully upgraded and new resources added for security. The recommendations for this strategy are: provide access control (create rules), create identification and authentication management, add more software and hardware protection (firewalls), limit user access into the cloud, add software protection (antivirus), create permissions rules, monitor the data access, backup cloud data, add more network resources, add redundancy, and increase bandwidth capacity.

(5) Avoid Deploy To Cloud

In this strategy, the recommendation is to avoid moving to cloud manufacturing. This recommendation is based on the level of security in the cloud. The impact of uncertainty factors on confidentiality, integrity, and availability are very high on security in the cloud. The security in this situation is very challenging and can be costly for organisations that are using or considering adopting cloud manufacturing.

6.6 Chapter Summary

Uncertainties in cloud manufacturing can be a major obstacle for cloud manufacturing implementation because of the nature of uncertainty that contains both unquantifiable and quantifiable factors and provides little information about the uncertainty complexity. In this chapter, the Simple Multi-Attribute Rating Technique (SMART) and a fuzzy rule-based system (FRBS) were used to assess uncertainty factors in cloud manufacturing. Development of a knowledge base for security and privacy uncertainty factors was elucidated in this chapter.

The Simple Multi-Attribute Rating Technique (SMART) has been presented as an approach to measure the importance (weight) of uncertainty in cloud manufacturing. This approach uses experts' or stakeholders' judgement to weight the importance of each uncertainty in four different dimensions. As a result, this approach delivers a ranking system for uncertainties that can be used to determine strategies and facilitate decisions on how to deal with uncertainty in cloud manufacturing.

In the second part of the assessment, a fuzzy rule-based system (FRBS) has been applied to quantify security and privacy uncertainty factors. This technique can characterise uncertainty within the problem. The fuzzy rule-based system used employs knowledge from experts to quantify security and privacy uncertainty factors. The development of a fuzzy rule-based system starts with identifying input and output variables through literature and experts' opinions. Next fuzzy rules and membership functions for each input and output variable are created. Mamdani's fuzzy inference system is then applied. Finally, the fuzzy results are converted into a crisp output by using the Centre of Gravity method for Defuzzification.

A knowledge base that provides recommendations and solutions to control and deal with security and privacy uncertainty factors in cloud manufacturing was created as the final part of the fuzzy rule-based system. The knowledge base is divided into two bases: classification base that classifies the security model's components; and recommendation base that offers strategies for decision makers to deal with uncertainties in cloud manufacturing.

7 UNCERTAINTY ASSESSMENT TOOL AND VALIDATION

7.1 Introduction

The aim of this chapter is to describe the development process of the uncertainty management software tool, and to present the implementation of the uncertainty management framework in a real-life context through case studies. The framework was embedded in an online tool which facilitates case studies analyses and discussions. In addition, three case studies and expert opinion were used to fulfil the final objective of this research, which is validating the framework by these means.

The verification process was conducted with six experts in the field of Information Technology. Moreover, the validation process was carried out across different industries that include a CAD/CAM programming company, a government organisation involved in public services, and a military organisation. The chapter is structured as follows: Section 7.1 provides a brief introduction of the chapter; Section 7.2 describes the development process of the uncertainty management framework tool; Section 7.3 presents an overview of verification and validation processes; Section 7.4 presents the chapter summary.

7.2 Uncertainty Management Framework Implementation

7.2.1 Tool Development

The purpose of this section is to describe the development process of the uncertainty management framework tool by providing full details for how this tool was built, based on the uncertainty management framework. The tool is made up of three modules. A knowledge base module provides information about uncertainties and cloud manufacturing for the tool's users. A ranking module identifies and prioritises uncertainties in cloud manufacturing. An assessment module quantifies security and privacy uncertainties that exist in cloud manufacturing. The framework is presented in Chapters 5.

To implement the uncertainty management framework, the author decided to develop an online tool that can be easily accessed over the Internet and allows organisations to manage the uncertainties in cloud manufacturing through the web. The uncertainty management framework was embedded in an online tool by using: Visual Studio Application for coding and creating the tool as a website; Microsoft Azure for hosting the tool over the Internet, by using a cloud computing platform and infrastructure; and MATLAB Application for analysing and simulating fuzzy logic system.

Microsoft created both Visual Studio and Azure. Visual Studio is an integrated development environment (IDE) with a complete set of development tools for building ASP.NET Web applications, XML Web Services, desktop applications, and mobile applications. It supports different programming languages such as Visual Basic, Visual C#, F#, and Visual C++. Azure is a cloud computing platform and infrastructure that allows hosting websites and databases.

MATLAB is a tool for numerical computation and visualisation. It allows mathematical operations such as matrix manipulations, plotting of functions and data, implementation of algorithms, the creation of user interfaces, and interfacing with programs written in various programming languages, such as C, C++, Java, Fortran, and Python.

7.2.2 Tool Architecture

The uncertainty management framework tool is composed of three modules: knowledge base module, ranking module, and assessment module. The knowledge base module helps users to understand uncertainties and cloud manufacturing. The ranking module references the relevant uncertainties, and prioritises those uncertainties by measuring their importance (weight) in cloud manufacturing. The assessment module quantifies security and privacy uncertainties through fuzzy modelling. A flowchart of the assessment tool is presented in Figure 7-1.

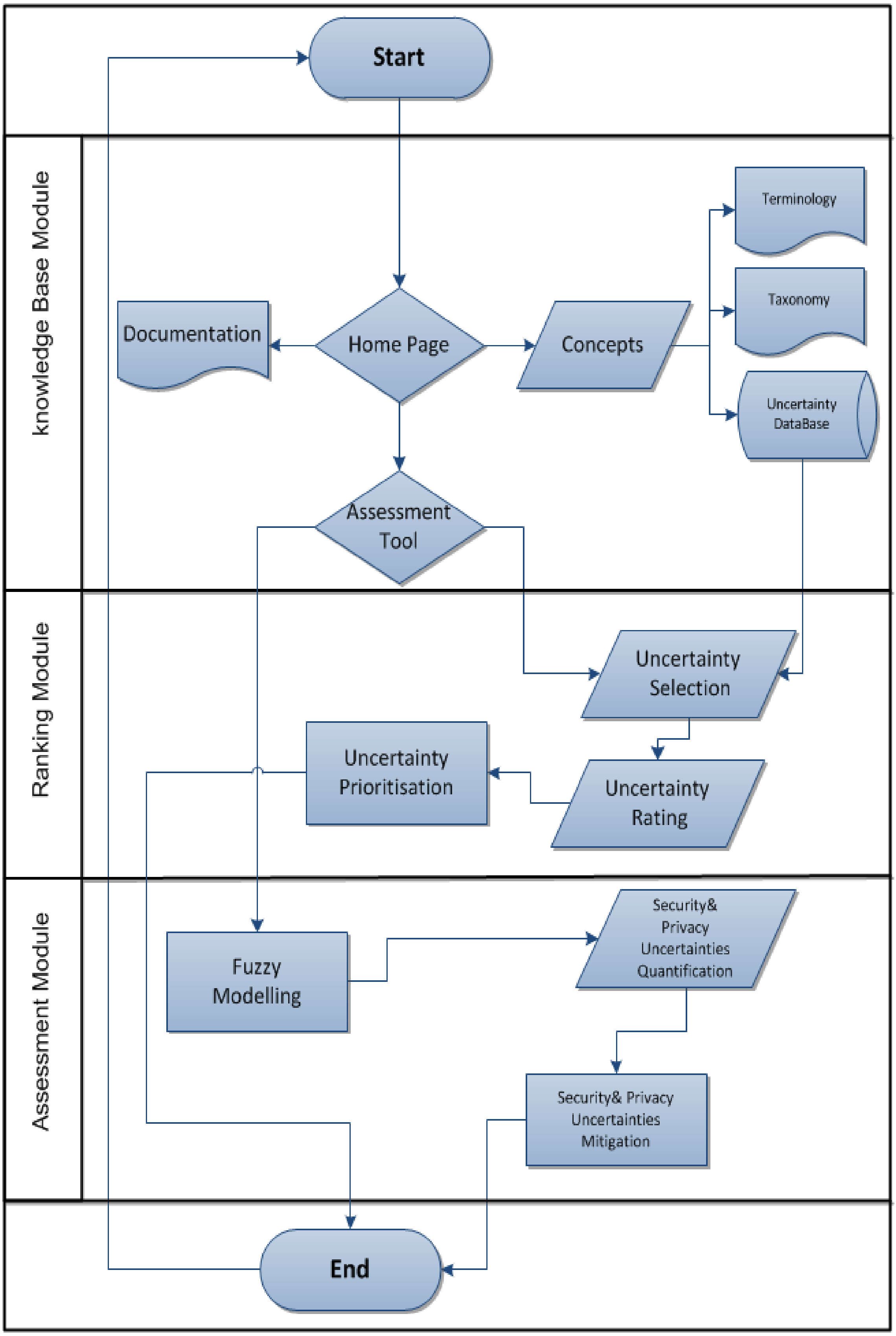


Figure 7-1: Assessment tool flowchart

7.2.2.1 Knowledge base module

This module provides all essential information that is needed to implement the uncertainty management framework tool by providing the tool's documentation and concepts. It is also required in order to understand the cloud manufacturing concept through presenting a cloud manufacturing taxonomy, and to eliminate confusion regarding uncertainties by building an uncertainty database. The elements of the knowledge base module are:

- Home page: the main page when the user accesses the tool online. It acts as an index that helps users navigate to other pages in the tool. Also, it provides information about the tool and provides a brief presentation to explain the aim of tool and what the assessment will accomplish. Figure 7-2 shows a screenshot of the Home page.
- Documentation page: provides information that describes the tool's development and provides a manual on how to use this online tool.

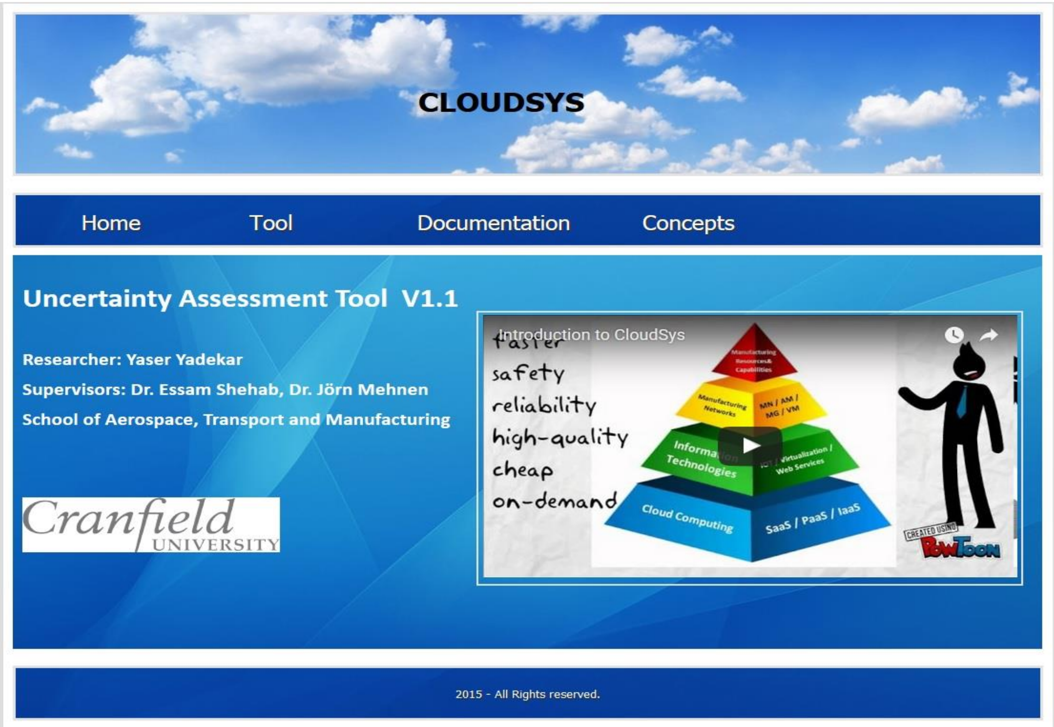


Figure 7-2: Screenshot of home page

- Basic Definitions page: introduces terminology that is used in the tool. This can help users to clarify the meanings of uncertainty, cloud manufacturing, and other new terms.

- Uncertainty Database page: presents a comprehensive collection of information regarding uncertainties in cloud manufacturing. 32 uncertainties with their descriptions are categorised according to three categories. This database can easily retrieve information based on the uncertainty category. Figure 7-3 shows a screenshot of uncertainty database page.

Figure 7-3: Screenshot of uncertainty database page

- Taxonomy page: defines and classifies all aspects of cloud manufacturing in a well-organised structure. This taxonomy provides a better understanding of cloud manufacturing, and helps to identify characteristics and attributes of cloud manufacturing.

  The taxonomy describes cloud manufacturing as a manufacturing model that provides a platform for collaborations between different users (consumers, manufactures, supplies) to achieve their goals by using the latest information technologies (cloud computing, IOT, virtualisation, Web service) and advanced communications networks (Manufacturing Network, Agile Manufacturing, Manufacturing Grid). This model has three primary stakeholders (cloud users, cloud resource providers, cloud operators), and consists of four different deployment models (public cloud, private cloud, community cloud, hybrid cloud) and two delivery models.

7.2.2.2 Ranking module:

A ranking module allows users to identify and prioritise uncertainties that exist in cloud manufacturing. The module process is conducted in three essential phases: identify all potential uncertainties, evaluate weight uncertainty, and rank each uncertainty according to the value of weight in cloud manufacturing.

The module begins with identifying uncertainties and by users themselves adding new uncertainties. The SMART technique is then applied for each relevant uncertainty to determine the weight of uncertainties in cloud manufacturing. This evaluation delivers a ranking system for the various uncertainties that is then used to determine strategies and decisions on how to deal with uncertainty in a cloud manufacturing. The elements of the ranking module are:

- Introduction page: gives brief details about assessment process.
- Selection Page: allows the user to identify existing uncertainties and add new uncertainties that exist in cloud manufacturing. This is an essential step to reference relevant uncertainties and prepare those uncertainties for evaluation. Figure 7-4 shows a screenshot of a selection page.

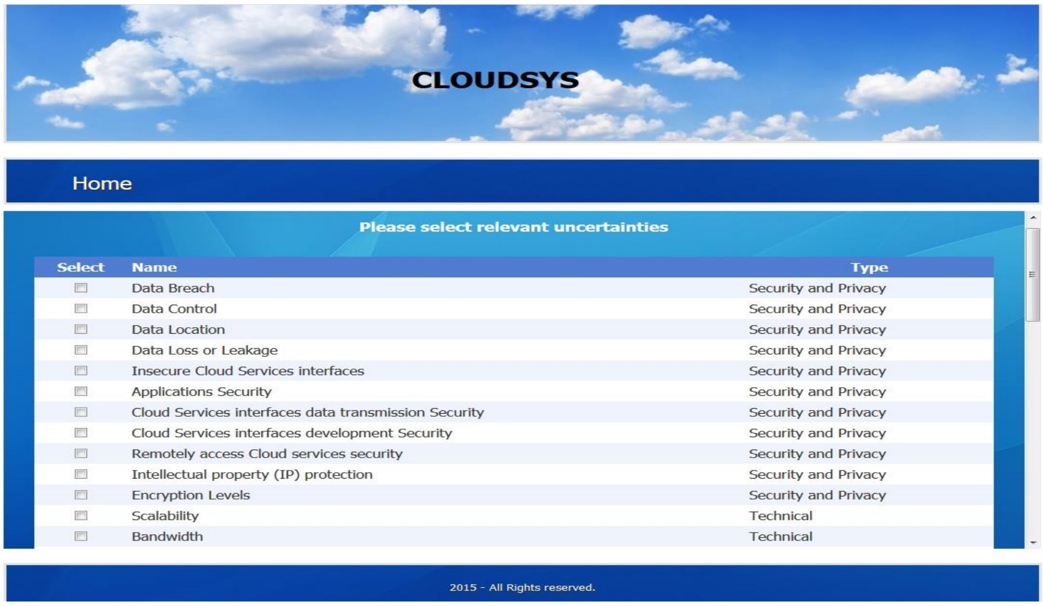


Figure 7-4: Screenshot of uncertainties selection

- Rating Page: allows the user to apply the SMART technique to determine the weight for each identified uncertainty. The user begins rating the dimensions by assigning numerical ratio judgments of the relative importance of attributes (on a scale from 10-100). Then, the SMART technique calculates the weight for each dimension by summing importance weight and dividing by total weight. The next step is to account for each uncertainty on each dimension with a value on a scale from 0-10. The SMART technique then calculates total weight for each uncertainty.
- Ranking Page: generates a report to provide information regarding uncertainty prioritisation based on their weight in cloud manufacturing. The ranking scores allow focusing attention on most critical uncertainties, and enable decision makers to determining strategies on how to deal with those uncertainties in cloud manufacturing. Figure 7-5 shows a screenshot of a ranking page.

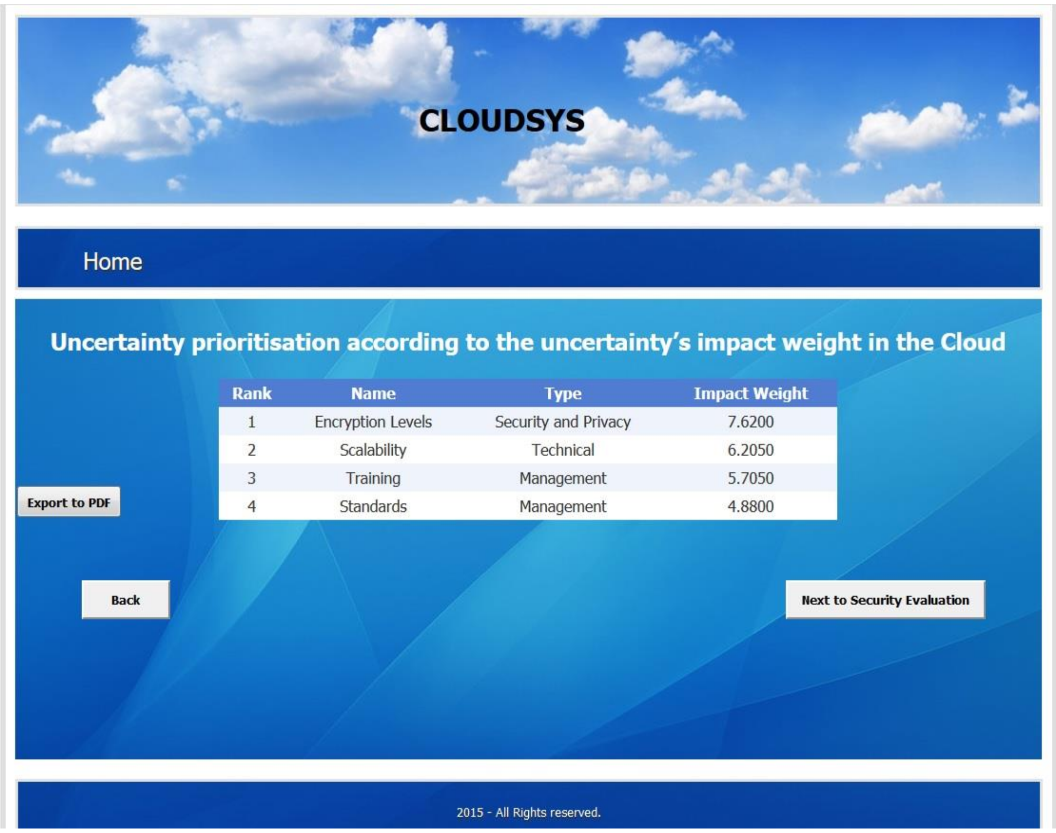


Figure 7-5: Screenshot of uncertainties ranking

7.2.2.3 Assessment module

This module is constructed based on a fuzzy logic approach. The approach applies fuzzy rule-based Mamdani modelling to quantify security and privacy uncertainties in cloud manufacturing. The module focuses particularly on security and privacy uncertainties due to the importance of those uncertainties in terms of confidentiality, integrity, and availability of cloud manufacturing.

The module begins with a brief outline of the components of the cloud security model (confidentiality, integrity, and availability), and provides an impact value table for security and privacy uncertainties. Next, the user begins to rate the elements of confidentiality / integrity / availability according to their impact on the level of security in the cloud. Finally, the outcome of this assessment is an analysis of cloud security level according to confidentiality level, Integrity level, and availability level. The assessment module also provides strategies to assist decision makers when moving to the cloud and recommendations on how to deal with security and privacy uncertainties. Figure 7-6 shows a screenshot of a security and privacy analysis page.

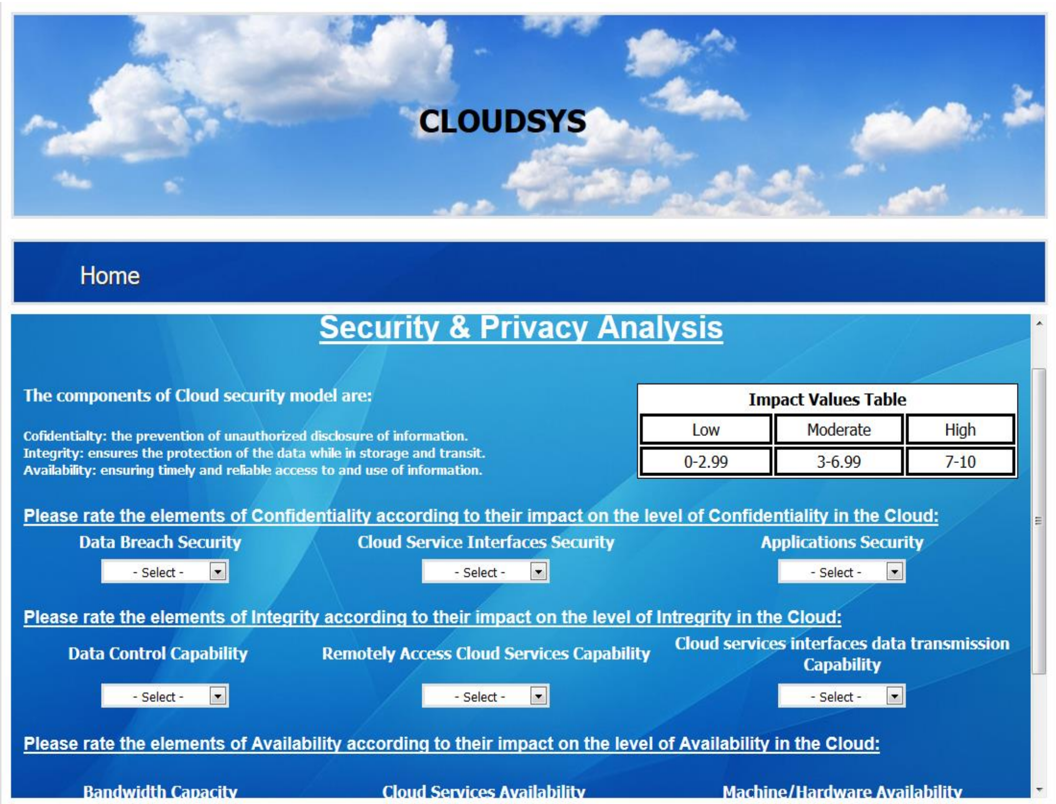


Figure 7-6: Security and privacy analysis

7.3 Uncertainty Management Framework Verification and Validation

The aim of the verification and validation process is to test the integrity of, improve, and analyse the framework and its tool. This section presents a verification process carried out with six experts in the Information Technology field, along with three case studies that were used to validate the framework and its tool.

7.3.1 Verification and Validation Methodology

The process of verification and validation was carried out through six experts and three case studies. The verification was conducted by asking a group of six experts in the Information Technology field to verify the framework's tool. The three case studies were to validate the framework and its tool. The aim of the first case study was to make improvements, identify limitations, and test the effectiveness of the framework and its tool. The last two case studies were to test worthiness and accuracy of the framework and its tool in an industrial environment. Figure 7-7 shows the verification and validation case studies methodology.

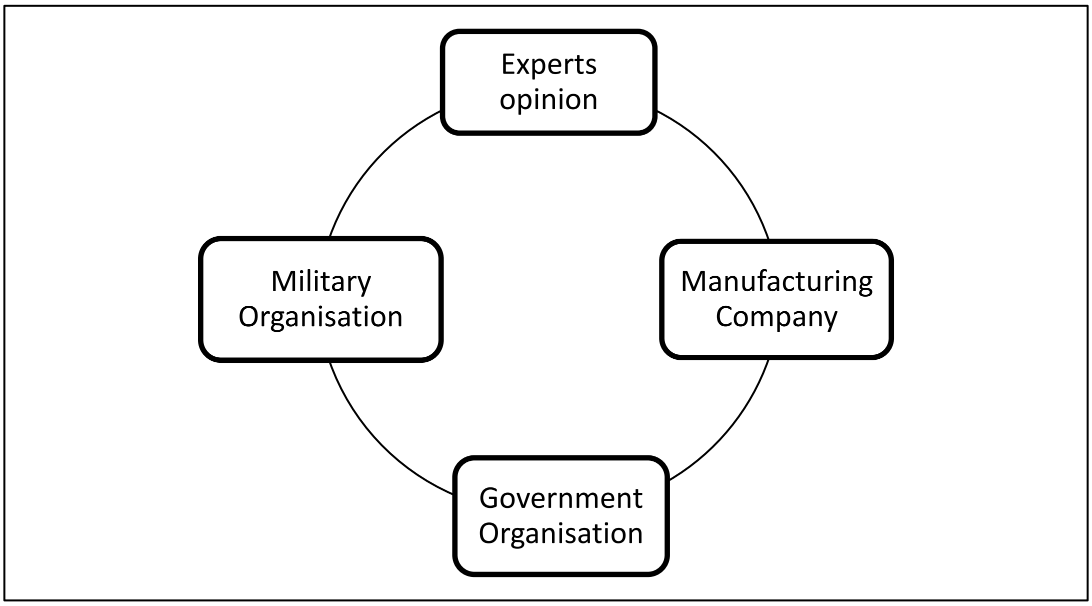


Figure 7-7: Verification and validation methodology

7.3.2 Tool Verification

Before embarking on the case studies, it was essential to conduct a verification process on the tool. The aim of the verification process was to test, inspect, and review the tool appropriately, and to make sure of its efficiency. As a starting point, the verification process began with selection of experts; six specialists in the field of Information Technology where selected. The Author contacted each expert to ensure their cooperation for the verification process. Table 7-1 shows details of the experts.

No	Expertise	Organisation	Role	Experience
1	Computer Engineering	Government Organisation (1)	IT Manager	24 Years
2	Computer Engineering	Government Organisation (2)	IT Head of Section	15 Years
3	Computer Engineering	Government Organisation (3)	Network Administrator	10 Years
4	Software Development	Government Organisation (4)	Software & web Developer	8 Years
5	Software Development	Private Company (1)	Web Developer	17 Years
6	Software Development	Education Institute	Instructor and Software Developer	15 Years

Table 7-1: Experts details

The verification process was conducted in four steps. The first step was to set up the tool online by using Azure hosting services to publish the tool. This step facilitated the verification process by allowing the experts to access the tool through the Internet. Secondly, an email invitation with the tool's website link was sent to the experts. The invitation contained information about the Ph.D. project and the aim of the verification process. The third step was to contact each expert before they began the validation process by phone, WebEx, or email to explain the tool and to resolve any questions. Finally, after trying the tool, the experts were asked to complete the verification questionnaire. The experts' responses to the questionnaire are presented in Table 7-2.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Mean
	1	2	3	4	5	
Q1			17%	33%	50%	4.3
Q2				33%	67%	4.6
Q3				83%	17%	4.1
Q4				33%	67%	4.6
Q5				33%	67%	4.6

Table 7-2: Experts' responses

- **Analysis of verification process:**

According to the experts' responses regarding the tool's interface, five experts agreed or strongly agreed that the tool's interface is well designed, easy to understand and operate. Expert (1) neither agreed nor disagreed, but suggested increasing clarity and adding more information, such as clear labelling to eliminate any ambiguity in the tool's Interface.

All experts agreed or strongly agreed that the information and instructions are easy to understand and follow. Expert (6) remarked that a few of the tool's pages were missing some buttons and information. Appropriate adjustments were made to ensure the functionality of tool. In addition, all experts agreed or strongly agreed that no bugs affected the tool; it was easy to navigate between pages without any problems; and the tool's performance is satisfactory and it functions properly.

7.3.3 Case Study (1): CAD & CAM Services Company

The first case study was conducted with a CAD/CAM services company to identify the tool's limitations and to make recommendations to improve the tool for the remaining case studies. The company provides a range of services in the area of CAD/CAM programming and offers support in the form of consulting services for introduction of modern technologies, such as high speed machining, hard machining and the selection of CAD/CAM systems for manufacturing companies.

Additionally, the CAD/CAM services company engaged was part of an EU-funded project to enhance the competitiveness of European companies, particularly SMEs, in a sustainable manufacturing environment. This is to be achieved by collaborative and adaptive process planning against changes; knowledge-based and integrated process simulation towards first-time-right processes; event-driven function blocks for on-board adaptive process control; machine availability monitoring for real-time job routing; and a cloud-based services platform for cost-effective and easy access over the Internet.

The researcher contacted a senior member of the company, a division manager, with a background in software engineering and 27 years' experience in the manufacturing industry. In addition, the division manager was involved in the EU-funded project to develop cloud manufacturing for SMEs. The validation began with an explanation of the aim and outcomes for this validation. Next, a short online presentation (fifteen minutes) gave a brief description of the tool and its characteristics. After this, the division manager was able to access the tool online to identify limitations and to make suggestions to improve the tool. Finally, the division manager was in a position to start to give feedback regarding the tool through discussion and completing the validation questionnaire.

Results obtained from this case study show that the tool can be useful for stakeholders to provide information regarding uncertainties in cloud manufacturing. However, there were limitations for using the tool, which is dependent upon the knowledge of tool's user. Also, there was a need for further explanation of both terminology and processes, and to modify some of the tool's functions. The division manager also suggested adding sample or dummy data to demonstrate how the tool works, to help the tool's user understand and clarify processes and concepts in the tool. Consequently, based on the participant's feedback and suggestions, more modifications were made to improve the framework and its tool.

7.3.4 Case Study (2): Government Organisation

The second case study was conducted to test the worthiness and accuracy of the tool by demonstrating the process of identifying and prioritising uncertainties in an industrial environment. The implementation of the tool was in a government organisation that established an integrated management system for infrastructure maintenance. The aim of this system is to accurately determine, in a scientific way, the maintenance needs of highways, government buildings, sewer networks, and bridge networks. In addition to maintenance needs, the system provides inventory management for all infrastructure and maintenance projects. It also conducts continuous assessment of the state of each part of the infrastructure network's components.

The integrated management system for infrastructure maintenance connects the government organisation with the other organisations (government and private) to ensure coordination of maintenance work, to avoid overlap, and to develop integrated plans and programs for maintenance work. The system network depends on servers that exist in each organisation and connect to the main server in government organisation's headquarters. All requests for ordering or manufacturing parts for the projects are carried out manually.

In this case study, the government organisation was considering implementing a cloud manufacturing solution for the integrated management system for infrastructure maintenance. The idea was to use cloud technology for collecting real-time data from project sites, and then order or have parts manufactured from other organisations for the maintenance projects.

The validation session begins with a short presentation (15 minutes) to give a brief description of the research and to demonstrate the tool by using sample data. The researcher clarified any aspect of the tool during the session. Next, the participants started to select relevant uncertainties for their system. Some new uncertainties were added that the participants considered important in their system. A total of 17 uncertainties were chosen and made ready for assessment. The participants then ranked the dimensions according to their judgement and experience as follows: Security = 90, Performance = 80, Regulatory = 10, Cost = 50, as shown in Figure 7-8.

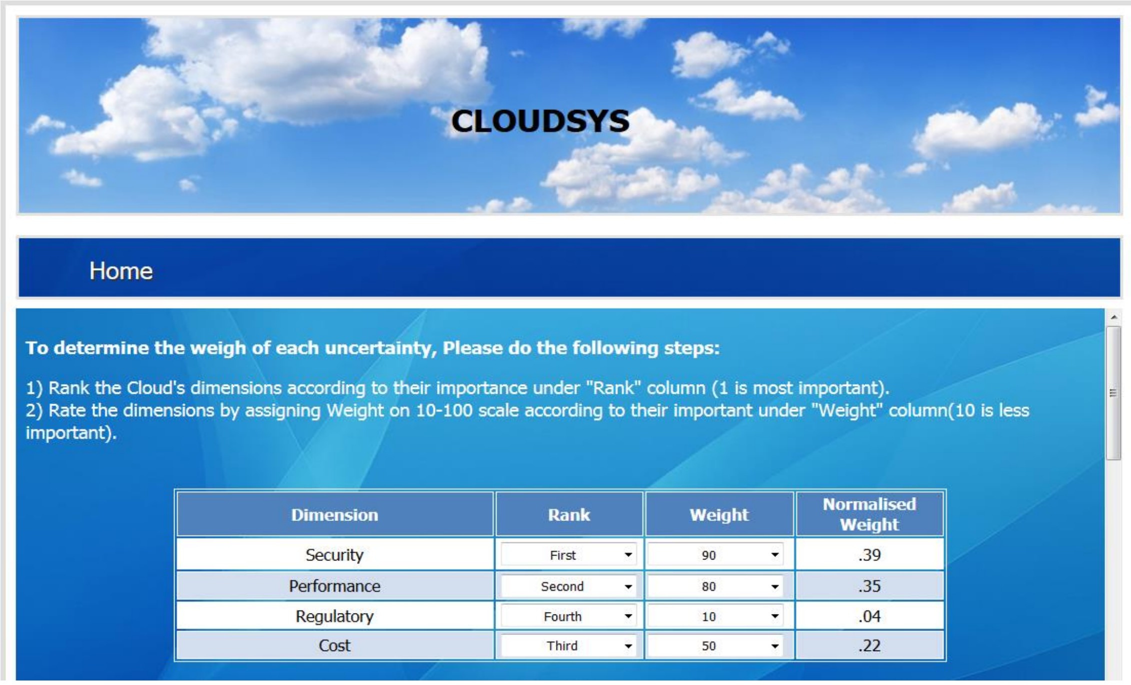


Figure 7-8: Dimensions ranking

After ranking the dimensions, the participants rated the uncertainties according to their weights in the system. Figure 7-9 illustrates the ranking process.

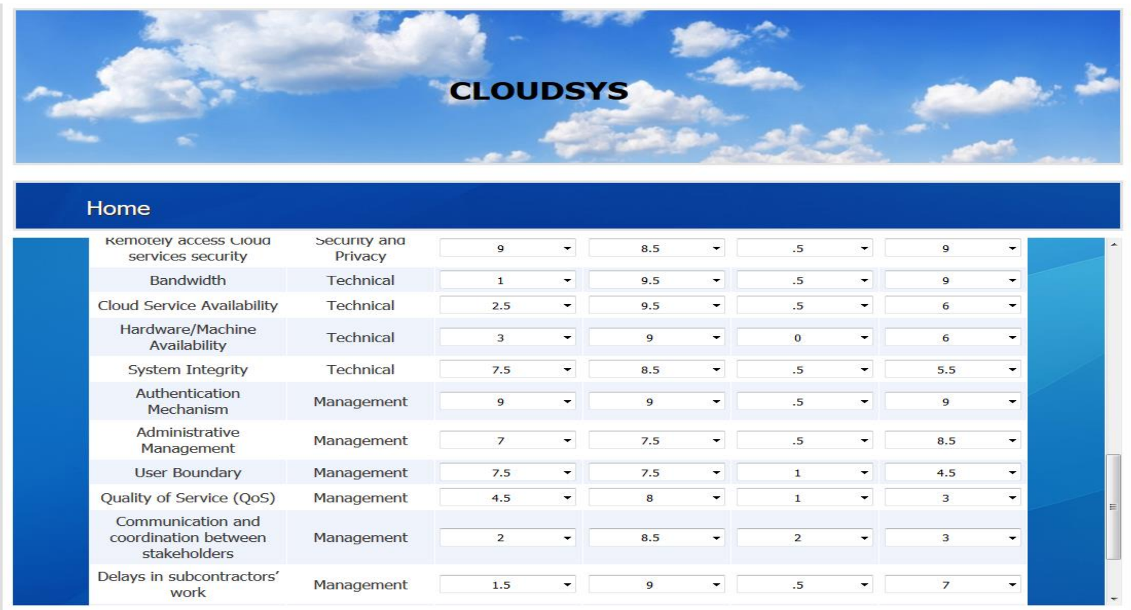
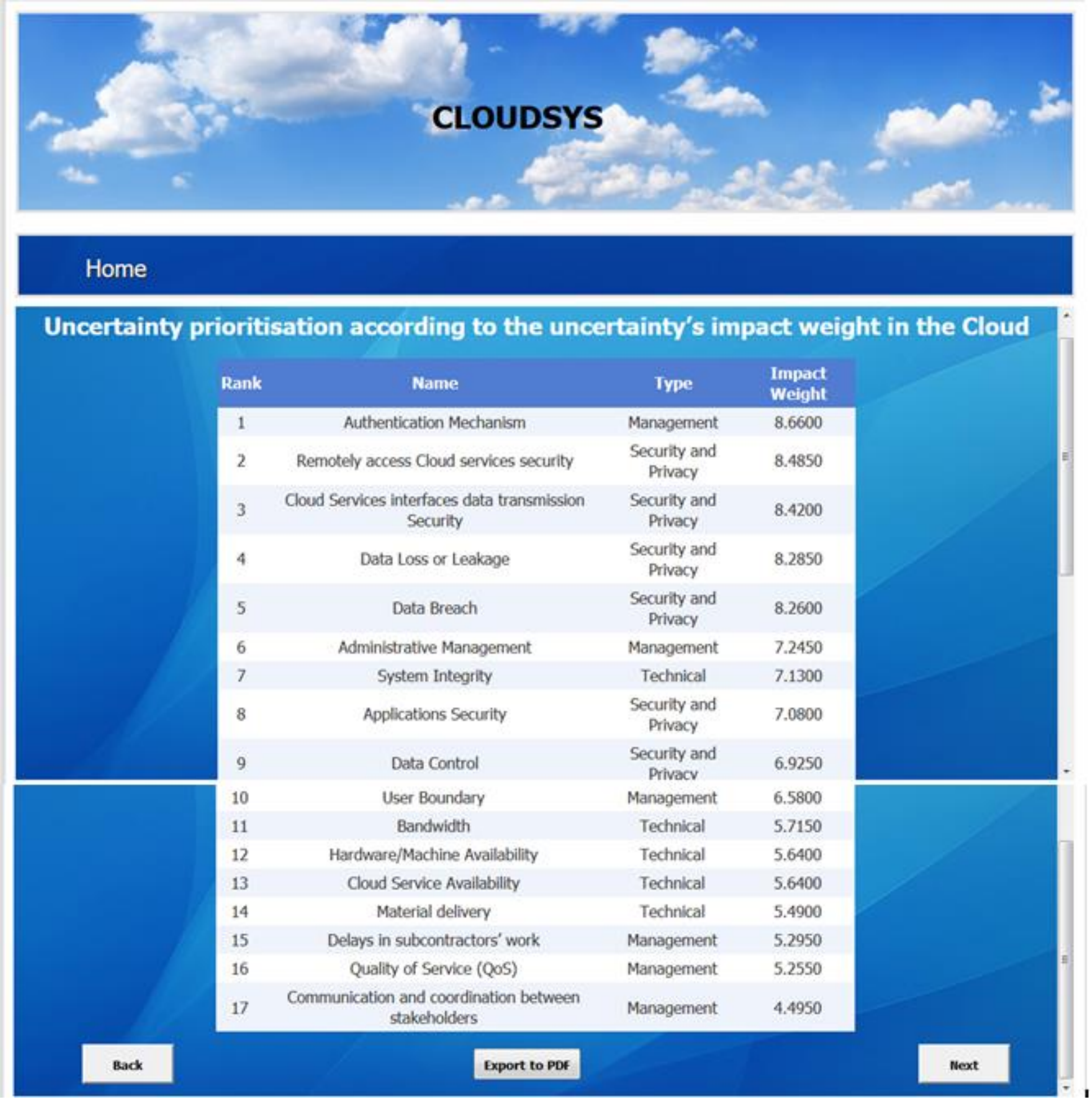


Figure 7-9: Ranking process

Finally, after calculation of each relative uncertainty weight, a report was generated that determined most-to-least-critical importance of uncertainties in the integrated management system for infrastructure maintenance. The results of assessing uncertainties in the integrated management system can be seen in Figure 7-10.



Rank	Name	Type	Impact Weight
1	Authentication Mechanism	Management	8.6600
2	Remotely access Cloud services security	Security and Privacy	8.4850
3	Cloud Services interfaces data transmission Security	Security and Privacy	8.4200
4	Data Loss or Leakage	Security and Privacy	8.2850
5	Data Breach	Security and Privacy	8.2600
6	Administrative Management	Management	7.2450
7	System Integrity	Technical	7.1300
8	Applications Security	Security and Privacy	7.0800
9	Data Control	Security and Privacy	6.9250
10	User Boundary	Management	6.5800
11	Bandwidth	Technical	5.7150
12	Hardware/Machine Availability	Technical	5.6400
13	Cloud Service Availability	Technical	5.6400
14	Material delivery	Technical	5.4900
15	Delays in subcontractors' work	Management	5.2950
16	Quality of Service (QoS)	Management	5.2550
17	Communication and coordination between stakeholders	Management	4.4950

Figure 7-10: Uncertainty prioritisation report

The outcomes of this case study show that the uncertainty assessment tool was helpful and able to identify uncertainties, and also determine the most important uncertainties according to their weight in the integrated management system. The tool helps stakeholders to gain knowledge regarding uncertainties in cloud manufacturing.

Furthermore, the participants communicated that the online uncertainty assessment tool could play a significant role in the process of using or adopting cloud manufacturing. However, concern was expressed regarding concepts and terminology; some uncertainty factors may have a different meaning depending on the tool's users. It was agreed that the tool is comprehensive and covers key aspects of cloud manufacturing and uncertainty factors in cloud manufacturing. The generalisability of the framework was also commended. The framework can be easily applied in any industry that is using or considering adopting cloud manufacturing.

Participants reported that the tool provides detail and clarification of cloud manufacturing in the form of a taxonomy. This taxonomy allows understanding the role of uncertainties when using cloud manufacturing by providing a detailed description of each uncertainty in cloud manufacturing. In addition, the tool allows the users to recognise the most critical uncertainties from the prioritising process, and can help stakeholders deal with uncertainties by providing mitigation strategies. On the other hand, the tool requires a user with knowledge in uncertainties and cloud technology to be able to use the tool in an ideal way.

7.3.5 Case Study (3): Military Organisation

The last case study was conducted to test worthiness and accuracy of the tool by showing the process of quantifying security and privacy uncertainties, and the providing recommendations on how to deal with security and privacy uncertainties in a cloud manufacturing environment. The implementation of the tool was in a military organisation responsible for accommodating the various needs of the armed forces and other military sectors through development, manufacturing, Information Technology operation, assembly, and supply. The military organisation was considering implementing a cloud manufacturing solution to achieve integration among the military organisation, other military sectors, and government agencies.

The primary concerns for the military organisation before adopting a cloud manufacturing solution were security and privacy issues. So, by using the assessment tool, the decision makers in the military organisation were able to evaluate the impact of security and privacy uncertainties through the uncertainty quantification method. The tool also presented strategies and recommendations for moving to the cloud.

The session started with a 15 minute presentation to give a brief description of the research and to demonstrate the tool by using sample data. The researcher clarified any aspect of the tool during the session. The participant began by rating the elements in the information security model (Confidentiality – Integrity – Availability). For each component of the CIA model, there were three uncertainty factors that needed to be rated according to the participant's expertise. Figure 7-11 shows the ranking process for the CIA model's components.

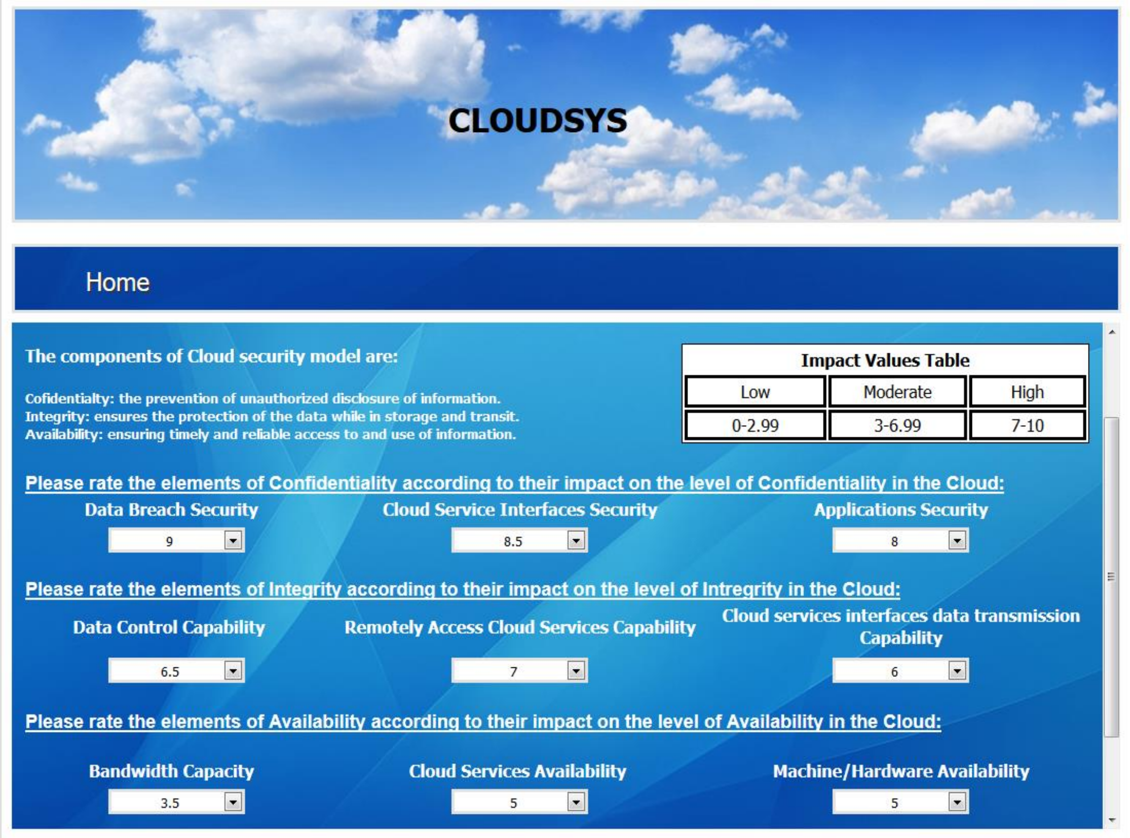


Figure 7-11: CIA model's components ranking process

Each component of the CIA security model has three uncertainty factors, making a total of nine uncertainty factors for all components. Each uncertainty factor was rated according to its effect on the levels of the three components of CIA security. The relationship between uncertainty factors and their components demonstrates an inverse relationship. An increase in the value of the uncertainty factor results in a decrease in the value of the component of CIA security.

The participant agreed on values for each uncertainty after lengthy discussion with the researcher: the confidentiality uncertainty factors were considered the most critical uncertainties that may affect cloud manufacturing security level in the organisation. Moreover, both availability uncertainty factors and integrity uncertainty factors were considered to have the same level of effect on cloud manufacturing security level in the organisation.

Finally, the results of cloud manufacturing security level analysis were displayed on the solution page as shown in Figure 7-12. The analysis includes three outcomes: the impact of uncertainty factors on each level of the CIA security model's component; the diagnoses of three levels of the CIA security model's components; and the decision that provides advice on how to move to the cloud along with recommendations.

Figure 7-12: Security level analysis

The results from the military organisation case study show that the confidentiality level is 16%. This indicates that the impact of the confidentiality uncertainty factors on the security level is high, and can cause severe or catastrophically adverse effects on cloud manufacturing operations, cloud manufacturing assets, or cloud manufacturing users. Integrity level and availability level are 45% and 55% respectively. These outcomes point out that the impact of uncertainty factors of both integrity and availability on the security level are moderate, and can cause seriously adverse effects on cloud manufacturing operations, cloud manufacturing assets, or cloud manufacturing users.

The participant received a decision that stated: “Deploy to cloud with Major Recommendations”. This decision advised the participant to choose the option of moving to the cloud with suggestions to increase the security level in cloud manufacturing. It was suggested to add and upgrade software programs, add and improve hardware resources, and create and update access controls rules.

The participant in the military organisation considered the uncertainty assessment tool to be very helpful for analysis of security in the cloud. Moreover, it can easily remove the ambiguity of uncertainties by applying fuzzy rule-based system to quantify linguistic variables. The tool helps to realise what modifications are needed to successfully implement cloud manufacturing. The participant from the military also agreed with participants from the previous case studies regarding the generalisability of the framework.

On the other hand, the participant expressed a desire for a more detailed explanation of concepts, terminology, and processes. This would simply clarify any confusion about using the tool. The assessment processes might also seem complicated and a challenge for the tool’s users. From the participant’s point of view, a development a manual that gives instructions on how to use the tool and provides information on the processes would be very helpful to facilitate the utilization of the tool.

7.4 Chapter Summary

This chapter demonstrates the implementation of the uncertainty management framework in a real life context. The first part of the chapter shows the process of the development of the framework in the form of an online assessment tool. While in the second part of chapter, interviews with experts and three case studies from different industries were presented for verification and validation.

The tool developed is in the form of a website, and it can be accessed from anywhere at any time. Its main function is to analyse uncertainties in cloud manufacturing. The tool is composed of three modules: knowledge base module, ranking module, and assessment module. In addition, the verification process has been conducted with six experts in the field of Information Technology. Whereas case studies were to validate the framework and its tool, the aim of first case study was to test the effectiveness of the framework and its tool. The aims of other case studies were to test worthiness and accuracy of the framework and its tool.

8 DISCUSIONS AND CONCLUSIONS

8.1 Introduction

The aim of this chapter is to outline the research findings, summarise the research results, draw conclusions and make recommendations for future work. In this chapter, the author commences by discussing the outcomes from this research that include findings from literature, the research methodology, development of an uncertainty framework, validation of the uncertainty framework, research contribution, research limitations, and future work. The chapter also reveals answers to the research aim and objectives, and presents overall research conclusions. The chapter is divided into four sections: Section 8.1 introduces the chapter aim; Section 8.2 discusses the research findings and results; Section 8.3 presents the conclusions for this research; and finally, Section 8.4 gives recommendations for potential directions of future work in the cloud manufacturing research field.

8.2 Discussion

In this section, the author provides a review and discussion on the key findings of the research project. This section explains the results based on the author's interpretation and opinions.

8.2.1 Literature Review

The researcher has conducted a comprehensive review related to two main areas, cloud manufacturing and uncertainties (Chapter 2). This investigation was necessary in order to understand the research aspects, and to establish a theoretical background for research topic (cloud manufacturing and uncertainties). In this research, cloud manufacturing was highlighted as a new field for scientific research related to the existing discipline of Information Technology. This emerging concept has drawn the attention to many of scholars in the research community. The number of studies regarding cloud manufacturing has increased dramatically over the period 2013 – 2016, up from 99 research papers to 591 (from Scopus bibliographic database). This demonstrates the growing importance of the cloud manufacturing research field in both industry and the research community.

The researcher discovered that there is no consensus among scholars regarding a definition of cloud manufacturing. This ambiguity may cause misunderstanding regarding its actual meaning. Moreover, research in cloud manufacturing has tended to focus on the technical aspects, such as its architecture and its enabling technologies. This has led to the managerial point of view in cloud manufacturing being negected, and a lack of research towards implementing cloud manufacturing in a real life context.

In the second part of the review, the researcher investigated uncertainty and its role in cloud manufacturing. The investigation revealed that there are different understandings of the meanings of uncertainty and risk, where every field of study has its own explanation these two concepts. In addition, there are a limited number of studies on the role of uncertainties in cloud computing or cloud manufacturing. This research highlighted the significance of addressing uncertainties in cloud manufacturing by developing a guide to manage uncertainty in cloud manufacturing at the adoption level as well as the implementation level.

8.2.2 Research Methodology

Chapter 3 details how the research was carried out. Due to the fact that cloud manufacturing is considered a new concept and is in an emerging field of science, there are very few studies in this area. It is difficulty to collect quantitative data because of the lack of historical data or previous knowledge of situations in cloud manufacturing. The research followed an exploratory approach to seek answers and new insights regarding cloud manufacturing. In addition, a qualitative method was applied in this research because of the convenience and flexibility when collecting data, analysing data, and interacting with experts.

Objectivity was a major issue in this research. The researcher therefore engaged in various activities of data collection to enhance objectivity. The data collection activities included: literature review (journal papers, reports and documents), face-to-face interviews, online interviews, phone interviews, online questionnaires, two rounds of the Delphi survey, and workshops with experts. Moreover, another strategy to enhance objectivity is to collect data from individuals and experts that come from different backgrounds and organisations.

8.2.3 Understand Cloud Manufacturing

One of most significant finding from the literature is the misunderstanding of cloud manufacturing as a concept. Chapter 4 presents a comparison between traditional manufacturing and cloud manufacturing. The goal of this comparison is to demonstrate the similarities or dissimilarities between traditional manufacturing and cloud manufacturing. A questionnaire was also developed and distributed to capture requirements, measure the awareness, and identify challenges of cloud computing technology in the manufacturing environment. Moreover, to emphasize the importance of understanding cloud manufacturing, a taxonomy to provide a description and classification of all aspects of cloud manufacturing in a well-organised structure was introduced. This taxonomy demonstrates a comprehensive understanding of cloud manufacturing's key areas and its main enabling technologies.

8.2.4 Framework Development

Following analysis of the research findings, a novel framework to manage uncertainty in cloud manufacturing was proposed. The goal of this framework is to provide new insights on the role of uncertainties, and to present solutions and strategies to deal with uncertainties at adoption and implementation stages of cloud manufacturing. This framework offers a detailed step-by-step approach to understand, highlight, analyse, quantify, and control the most critical uncertainties that exist in cloud manufacturing. In addition, the framework was embedded in an online tool (web site) to promote cloud manufacturing as new manufacturing paradigm and to facilitate case studies analyses and discussions.

The elements of the framework are: understand the context, identification, assessment, and control. The first element involves concepts, terminology, and relationships in cloud manufacturing. The second element provides a process to identify uncertainties in cloud manufacturing. This identification process enables documentation of uncertainties in the early stages of the cloud manufacturing development and implementation. Also, it contributes to creating a knowledge base for the uncertainties that exist in cloud manufacturing. The third element is to assess uncertainties based on two approaches: the Simple Multi-Attribute Rating Technique (SMART) to evaluate the weight of uncertainties; and a fuzzy rule-based system (FRBS) to quantify security and privacy uncertainties. The final element is responsible for applying strategies to control uncertainties in cloud manufacturing. A set of structured interviews with five professionals was conducted to acquire knowledge from their expertise. The results from those interviews were used to establish a knowledge base that contains recommendations and solutions to deal with and control security and privacy uncertainties in cloud manufacturing.

The researcher used SMART to calculate importance (weight) of uncertainty in cloud manufacturing. This technique uses experts' or stakeholders' judgment to weight the importance of each uncertainty in different dimensions. Also, the simplicity of the technique allows the organisations to enter the scores and weight of uncertainties straight forwardly. The outcome from this technique is a ranking system for each uncertainty to identify the most-to-least-critical importance uncertainty. This ranking system can be used to determine strategies and decisions on how to deal with uncertainty in cloud manufacturing.

A fuzzy rule-based system (FRBS) was used to quantify security and privacy uncertainties in cloud manufacturing. This technique is based on fuzzy logic, and employs human knowledge to create fuzzy IF-THEN rules. Moreover, this technique can characterise uncertainty within the problem, and clear any ambiguity in cloud manufacturing. The results of using this technique can be used to determine cloud manufacturing functionality under the existing uncertainty by providing recommendations and solutions to deal with security and privacy uncertainty factors in cloud manufacturing.

8.2.5 Framework Validation

The researcher implemented the uncertainty management framework in real life context through case studies. The case studies and expert elicitation were used to fulfil the last objective of this research which is validating the framework through case studies and expert opinion. The case studies emphasize the framework's generalisability, and the ability to handle uncertainty in different industries. Also, the outcomes from three case studies were employed in terms of making improvements in, and revealing the limitations, effectiveness, and worthiness of, the framework and its tool.

8.2.6 Fulfilment of Aim and Objectives

This section demonstrates the achievement of the four main research objectives outlined in Chapter 1. A description and discussion for each objective is given below:

1. **Capture requirements for cloud manufacturing and its types, characteristics and attributes.**
   In order to achieve this objective, a comprehensive literature review was conducted. The researcher also interacted with academia and industry professionals through interviews and questionnaires and cloud manufacturing and uncertainties were discussed in detail. This allowed the researcher to understand cloud manufacturing and its types, characteristics and attributes, and explore the role of uncertainty in manufacturing and its effects in the cloud environment. Also, the researcher presented a taxonomy for cloud manufacturing that offered a description and classification of all aspects of cloud manufacturing in a well-organised structure. This taxonomy was validated through interviews with two experts in the Information Technology and cloud technology fields.

2. **Develop a process to identify uncertainties in different types of cloud manufacturing for SMEs.**

   In order to achieve this objective, the researcher investigated the literature related to cloud manufacturing and uncertainties, and examined published technical reports related to issues, problems, challenges, and risks of cloud computing technology implementation in manufacturing in particular, as well as other sectors. Besides the previous step, a brainstorming session with two other researchers was conducted to generate an uncertainty factors list. An initial list of uncertainty factors for cloud manufacturing was delivered. The researcher concluded that as there was no emphasis on cloud manufacturing in the initial list of uncertainty factors, there was a need for in-depth interactions with industry and academia to refine this list.

   The next step was a survey and unstructured and semi-structured interviews with both academia and industry. The survey was based on the Delphi survey with two rounds, and involved 15 active researchers in the cloud manufacturing research field. Interviews were conducted with face-to-face or online meetings, and by phone or email. The researcher also participated in workshops and regular meeting with members of CAPP-4-SMEs project. As a result, an uncertainty factors list with 32 uncertainty factors was formulated from a cloud manufacturing perspective. Finally, the uncertainty factors list was validated through interviews with two experts with knowledge in cloud manufacturing and Information Technology, along with a group discussion with members of the CAPP project.

3. **Develop a framework and its software tool to assess and manage the uncertainty in a cloud manufacturing for SMEs.**

   In order to achieve this objective, the researcher developed a framework by incorporating both uncertainty management and the taxonomy into the framework. The taxonomy described and classified all aspects of cloud manufacturing in systematic structure. The uncertainty management allows the following activates: identify, assessment, and control of uncertainties in cloud manufacturing. In addition, the framework was embedded into an online tool that can be easily accessed over the Internet. The tool was developed by using Visual Studio Application for codding and creating the tool as website, Microsoft Azure for hosting the tool over the Internet, and MATLAB Application for analysing and simulating fuzzy logic systems.

4. **Validate the proposed framework through case studies and expert opinion.**

   In order to achieve this objective, the researcher conducted six interviews and three case studies for verification and validation of the framework and its tool. The interviews sought the opinion of six experts in the Information Technology field to verify the framework's tool, while the case studies were to validate the framework and its tool for different industries.

   After fulfilment all of the objectives, the researcher was able to achieve the aim of the research which is to develop a framework to manage uncertainty in cloud manufacturing for small and medium-sized enterprises (SMEs).

8.2.7 Key Research Contributions

1. **Cloud manufacturing taxonomy:** This research provides a novel and comprehensive classification of cloud manufacturing into six main areas in the form of a taxonomy for the cloud manufacturing literature. Also, this taxonomy can assist organisations in understanding, and support them in choosing, a suitable cloud manufacturing system.

2. **A detailed list of uncertainty factors:** This research added to knowledge in the area following the previous lack in the literature regarding uncertainties in cloud manufacturing. This research interacted with both academic and industry experts to capture the uncertainty factors within the cloud manufacturing perspective. This step introduced a detailed list of 32 uncertainty factors with their descriptions, and categorised them into three categories.

3. **A novel approach to prioritise uncertainties:** This research presents the Simple Multi-Attribute Rating Technique (SMART) as an approach to

measure the importance (weight) of uncertainty in cloud manufacturing. The outcomes from this approach created a ranking system for uncertainties, which can allow decision makers to determine the most-to-least-critical importance of uncertainties in cloud manufacturing.

4. **A novel approach to quantify security and privacy related uncertainties:** This research proposes a systematic process to quantify security and privacy uncertainties in terms of confidentiality, integrity, and availability of cloud manufacturing. The developed process employed fuzzy rule-based modelling to determine the outcomes of cloud manufacturing in the presence of uncertainties.

5. **A Knowledge base:** This research creates a knowledge base for security and privacy uncertainties in terms of confidentiality, integrity, and availability of cloud manufacturing. This knowledge base has been developed based on experts' opinions.

6. **A framework to manage uncertainty in cloud manufacturing:** This research introduced a framework that offers new insights for decisions makers on how to deal with uncertainty at adoption and implementation stages of cloud manufacturing. This framework enables organisations, who are trying to adopt or implement cloud manufacturing, to understand the role of uncertainty in a cloud manufacturing system, understand the cloud manufacturing itself, prioritise and quantify uncertainties, and provide solutions to deal with the uncertainties.

8.2.8 Research Limitations

The focus of the research is only on SME's manufacturing companies that are using, or considering adopting cloud manufacturing, but there were some research limitations. Firstly, the research quantified only the security and privacy uncertainty factors because of time restrictions. Also, the majority of organisations have their suspicions and fears about cloud manufacturing, and they are presently focusing only on security and privacy uncertainty factors.

Secondly, there are only a few experts with limited experience of cloud manufacturing in the world. Currently, all cloud manufacturing projects are under development or in the process of being studied. There are no real world examples of cloud manufacturing implementation in organisations. This meant that the research had to engage with experts from the different (although related) fields of Information Technology, cloud technology, and manufacturing for data collection, data analysis, and validation.

Thirdly, there was limited knowledge regarding cloud manufacturing because of to the nature of investigating a new field of research. There were difficulties in collecting data as there was no historical data or previous knowledge of cloud manufacturing. Consequently, the researcher applied qualitative methods for this research. Finally, the framework was validated only with one company that provides a range of services in the area of CAD/CAM programming for manufacturing companies and two non-manufacturing companies. This drawback did not allow illustrating the potential of the framework within manufacturing industry.

8.3 Conclusions

This research addresses an important issue in the manufacturing industry regarding implementing cloud technology in the manufacturing environment, known as cloud manufacturing. The following points summarise the main conclusions of this research study:

- Cloud manufacturing is one of the emerging technologies in the field of Information Technology, and has had a significant impact on manufacturing industry by enabling the sharing of manufacturing resources and capabilities as services, and creating collaboration.
- Applying new and complex technologies and networks (cloud manufacturing) in the manufacturing industry can create unknown and unpredictable situations, known as “uncertainties”.
- Uncertainties are considered as a major factor in cloud manufacturing. Understanding the role of uncertainties in cloud manufacturing can lead to

an enhanced understanding of an organisation's needs for adopting and implementing cloud manufacturing.

- The literature survey confirmed the lack of research directed towards how to manage uncertainties in cloud manufacturing. This research provides a framework to manage uncertainties in cloud manufacturing.

- The framework offers new insights for decisions makers to learn about cloud manufacturing itself, understand the role of uncertainty in cloud manufacturing, and provide solutions and strategies to deal with the most critical uncertainties at adoption and implementation stages of cloud manufacturing.

- The first part of the framework was based on the novel taxonomy of cloud manufacturing that decision makers use to gain knowledge and understand cloud manufacturing. While the second part of framework was based on uncertainty management principles.

- The Attribute Rating Technique SMART was used as one of the assessment methods to compute the importance (weight) of uncertainty in cloud manufacturing. With this technique it was possible to demonstrate the procedure to prioritise uncertainties according to their weight in cloud manufacturing. The results of this technique were presented in the form of a ranking system that shows most-to-least-critical importance of uncertainty factors in cloud manufacturing.

- The second assessment method employed a fuzzy rule-based system (FRBS) to quantify security and privacy uncertainties in cloud manufacturing, in a systematic process. The fuzzy technique enabled characterisation of the security and privacy uncertainties with regard to the CIA security model.

- A knowledge base was constructed to facilitate selecting recommendations and solutions for security and privacy uncertainties in cloud manufacturing. This knowledge base was able to deliver diagnoses and decisions for an organisation to deal with security and privacy uncertainties in cloud manufacturing.

8.4 Future Work

This PhD project has highlighted a number of themes around cloud manufacturing that could be beneficially explored in the cloud manufacturing research area. Suggestions include.

- Expand the current list of uncertainty factors to become uncertainty taxonomy that can demonstrate explicit link of the role of uncertainties in the manufacturing industry. This taxonomy would be useful in future with increase research and development of cloud manufacturing to understand and incorporate new uncertainties within cloud manufacturing.
- Extend the proposed framework to handle different types of cloud manufacturing. Whereas this research addresses only uncertainties in cloud manufacturing broadly, the framework could be expanded and all four types of deployment models in cloud manufacturing be investigated. Each type of deployment model in cloud manufacturing would need to be dealt with differently.
- Enhance the tool to involve different cloud manufacturing stakeholders. This will allow the tool to deliver an understandable outcome to a specific stakeholder group.
    - Improve the uncertainty identification process by incorporating new identification techniques, and address new and emerging uncertainties that evolve from using cloud manufacturing.
    - Apply new quantitative assessment methods on other categories of uncertainties in cloud manufacturing, and test the efficiency of these assessment methods on uncertainties.
    - Explore a number of management issues that include the lifecycle of cloud manufacturing; benefits of adopting cloud manufacturing; standards for migrating into cloud manufacturing, and for interoperability

between different clouds and in-house infrastructures; and the role and responsibility of stakeholders in a cloud manufacturing environment.

- Further investigation for cloud manufacturing implementation. There is a lack of cloud manufacturing implementation research in the literature. There is need for real life case studies and detailed data from different industries around the world for cloud manufacturing implementation.

REFERENCES

3D Creation Lab (2013) *About 3D Creation Lab, 3D Creation Lab*. Available at: http://www.3dcreationlab.co.uk/about_3d_printing_services.php (Accessed: 19 September 2013).

3Sourceful (2013) *About Us, 3Sourceful*. Available at: http://rbhax.com/about (Accessed: 18 September 2013).

Aien, M., Rashidinejad, M. and Fotuhi-Firuzabad, M. (2014) 'On possibilistic and probabilistic uncertainty assessment of power flow problem: A review and a new approach', *Renewable and Sustainable Energy Reviews*, 37, pp. 883–895.

Alhawari, S., Karadsheh, L., Nehari Talet, A. and Mansour, E. (2012) 'Knowledge-Based Risk Management framework for Information Technology project', *International Journal of Information Management*, 32(1), pp. 50–65.

Aliaga, M. and Gunderson, B. (2005) *Interactive Statistics*. 3rd edn. USA: Pearson.

Atzori, L., Iera, A., Morabito, G. and Nitti, M. (2012) 'The social internet of things (SIoT) - When social networks meet the internet of things: Concept, architecture and network characterization', *Computer Networks*, 56(16), pp. 3594–3608.

Azadegan, A., Porobic, L., Ghazinoory, S., Samouei, P. and Saman, A. (2011) 'Fuzzy logic in manufacturing : A review of literature and a specialized application', *Intern. Journal of Production Economics*, 132(2), pp. 258–270.

Babbie, E. (2012) *The practice of social research*. 13th edn. USA: Wadsworth Publishing.

Badger, L., Grance, T., Patt-Corner, R. and Voas, J. (2011) *Cloud computing synopsis and recommendations*. NIST Special Publication 800-146.

Booker, J. M. and Ross, T. J. (2011) 'An evolution of uncertainty assessment and quantification', *Scientia Iranica*, 18(3 D), pp. 669–676.

Bourguiba, M., Haddadou, K. and Pujolle, G. (2012) 'Packet aggregation based network I/O virtualization for cloud computing', *Computer Communications*, 35(3), pp. 309–319.

Bouwknegt, M., Knol, A. B., van der Sluijs, J. P. and Evers, E. G. (2014) 'Uncertainty of population risk estimates for pathogens based on qmra or epidemiology: A case study of campylobacter in the Netherlands', *Risk Analysis*, 34(5), pp. 847–864.

Butala, P. and Sluga, A. (2006) 'Autonomous Work Systems in Manufacturing Networks', *CIRP Annals - Manufacturing Technology*, 55(1), pp. 521–524.

CAPP-4-SMEs (2013) About Project, CAPP-4-SMEs. Available at: http://www.capp-4-smes.eu (Accessed: 5 March 2013).

Cheng, M. and Lu, Y. (2015) 'Developing a risk assessment method for complex pipe jacking construction projects', *Automation in Construction*, 58, pp. 48–59.

Chow, R., Golle, P., Jakobsson, M., Shi, E., Staddon, J., Masuoka, R. and Molina, J. (2009) 'Controlling Data in the Cloud: Outsourcing Computation without Outsourcing Control', in *Proceedings of the 2009 ACM workshop on Cloud computing security*. Chicago, IL; United States, 9-13 November 2009, pp. 85–90.

CloudSME (2013) cloudSME Overview, CloudSME. Available at: http://cloudsme.eu/content/cloudsme-overview (Accessed: 10 June 2014).

Cloud-based Rapid Elastic MAnufacturing (CREMA) (2015) About the CREMA project, CREMA. Available at: http://www.crema-project.eu/project (Accessed: 15 May 2015).

Cloud Industry Forum (2014) *NHS takes first step to storing patient information in the Cloud*. Available at: https://www.cloudindustryforum.org/content/nhs-takes-first-step-storing-patient-information-cloud (Accessed: 16 September 2014).

Cloud Security Alliance (2010) *Top Threats to Cloud Computing*, *Cloud Security Alliance (CSA)*. Available at: https://cloudsecurityalliance.org/topthreats/csathreats.v1.0.pdf (Accessed: 20 August 2013).

CreateSpace (2013) *About Us, CreateSpace*. Available at: https://www.createspace.com/AboutUs.jsp (Accessed: 10 September 2013).

Creswell, J. W. (2014) *Research design: Qualitative, quantitative, and mixed methods approaches*. 1st edn. UK: Sage publications.

Darbra, R. M., Eljarrat, E. and Barceló, D. (2008) 'How to measure uncertainties in environmental risk assessment', *TrAC - Trends in Analytical Chemistry*, 27(4), pp. 377–385.

Dupré, L. and Haeberlen, T. (2009) *Cloud Computing - Benefits, Risks and Recommendations for Information Security*, *The European Network and Information Security Agency (ENISA)*. Available at: https://resilience.enisa.europa.eu/cloud-security-and-resilience/publications/cloud-computing-benefits-risks-and-recommendations-for-information-security (Accessed: 3 September 2013).

Durbach, I., Lahdelma, R. and Salminen, P. (2014) 'The analytic hierarchy process with stochastic judgements', *European Journal of Operational Research*, 238(2), pp. 552–559.

Durbach, I. N. and Stewart, T. J. (2012) 'Modeling uncertainty in multi-criteria decision analysis', *European Journal of Operational Research*, 223(1), pp. 1–14.

Easterby-Smith, M., Thorpe, R. and Jackson, P. (2012) *Management research*. 4th edn. UK: Sage Publications.

Edwards, W. (1971) 'Social utilities', *Engineering Economist, Summer Symposium Series*, 6(1), pp. 119–129.

Edwards, W. and Barron, F. H. (1994) ‘SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement’, *Organizational Behavior and Human Decision Processes*, 60(3), pp. 306–325.

Eldred, M. S., Swiler, L. P. and Tang, G. (2011) ‘Mixed aleatory-epistemic uncertainty quantification with stochastic expansions and optimization-based interval estimation’, *Reliability Engineering and System Safety*, 96(9), pp. 1092–1113.

EPSRC Cloud manufacturing (2013) University of Nottingham. Available at: http://nottingham.ac.uk/ifam/research/collaborative/cloud.aspx (Accessed: 5 March 2014).

Erkoyuncu, J. A., Durugbo, C. and Roy, R. (2013) ‘Identifying uncertainties for industrial service delivery: A systems approach’, *International Journal of Production Research*, 51(21), pp. 6295–6315.

Erkoyuncu, J. A., Roy, R., Shehab, E. and Cheruvu, K. (2011) ‘Understanding service uncertainties in industrial product-service system cost estimation’, *International Journal of Advanced Manufacturing Technology*, 52(9-12), pp. 1223–1238.

Ernst and Young (2011) *Cloud computing issues and impacts*, *Global Technology Industry Discussion Series*.

European Commission (2012) *Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of regions*. Brussels. Available at: http://ec.europa.eu/euraxess/pdf/research_policies/era-communication_en.pdf (Accessed: 26 June 2013).

European Commission (2013) *Small and medium-sized enterprises (SMEs)*. Available at: http://ec.europa.eu/enterprise/policies/sme/index_en.htm (Accessed: 26 June 2013).

Funtowicz, S. O. and Ravetz, J. R. (1990) *Uncertainty and Quality in Science for Policy*. 1st edn. London: Springer.

Furht, B. and Escalante, A. (eds) (2010) *Handbook of cloud computing*. 1st edn. New York: Springer Publishing.

Gao, J., Yao, Y., Zhu, V. C. Y., Sun, L. and Lin, L. (2011) 'Service-oriented manufacturing: A new product pattern and manufacturing paradigm', *Journal of Intelligent Manufacturing*, 22(3), pp. 435–446.

Gao, N., Zhao, S. and Zhang, X. (2009) 'Research on the service-oriented manufacturing model', in *Proceedings of IEEM 2009 - IEEE International Conference on Industrial Engineering and Engineering Management*. Hong Kong, 8 December 2009, pp. 2431–2434.

Gao, X., Yang, M., Liu, Y. and Hou, X. (2013) 'Conceptual model of multi-agent business collaboration based on cloud workflow', *Journal of Theoretical and Applied Information Technology*, 48(1), pp. 108–112.

Gilbert, N. (2008) *Researching social life*. 3rd edn. UK: Sage publications.

Goodarzi, E., Ziaei, M. and Teang Shui, L. (2013) *Introduction to Risk and Uncertainty in Hydrosystem Engineering*. New York: Springer.

Goodwin, P. and Wright, G. (2014) *Decision Analysis for Management Judgement*. 5th edn. London: John Wiley and Sons.

Gubbi, J., Buyya, R., Marusic, S. and Palaniswami, M. (2013) 'Internet of Things (IoT): A vision, architectural elements, and future directions', *Future Generation Computer Systems*, 29(7), pp. 1645–1660.

Gunasekaran, A. (1998) 'Agile manufacturing: enablers and an implementation framework', *International Journal of Production Research*, 36(5), pp. 1223–1247.

Guo, L. (2016) ‘A system design method for cloud manufacturing application system’, *International Journal of Advanced Manufacturing Technology*, 84(1-4), pp. 275–289.

Harris Interactive (2010) *Novell Survey Reveals Widespread and Accelerating Enterprise Adoption of Private Clouds*. Available at: https://www.novell.com/news/press/2010/10/novell-survey-reveals-widespread-and-accelerating-enterprise-adoption-of-private-clouds.html.

Huang, B., Li, C., Yin, C. and Zhao, X. (2013) ‘Cloud manufacturing service platform for small- and medium-sized enterprises’, *International Journal of Advanced Manufacturing Technology*, 65(9-12), pp. 1261–1272.

Hubbard, D. W. (2014) *How to Measure Anything: Finding the Value of Intangibles in Business*. 3rd edn. New Jersey, USA: John Wiley and Sons, Inc.

Jato-Espino, D., Castillo-Lopez, E., Rodriguez-Hernandez, J. and Canteras-Jordana, J. C. (2014) ‘A review of application of multi-criteria decision making methods in construction’, *Automation in Construction*, 45, pp. 151–162.

Jayawardena, A. W., Perera, E. D. P., Zhu, B., Amarasekara, J. D. and Vereivalu, V. (2014) ‘A comparative study of fuzzy logic systems approach for river discharge prediction’, *Journal of Hydrology*, 514, pp. 85–101.

Kanwar, R., Narayan, U. and Lakshmi, V. (2010) ‘Web service based hydrologic data distribution system’, *Computers and Geosciences*, 36(7), pp. 819–826.

van Keur, P., Henriksen, H. J., Refsgaard, J. C., Brugnach, M., Pahl-Wostl, C., Dewulf, A. and Buiteveld, H. (2008) ‘Identification of major sources of uncertainty in current IWRM practice. Illustrated for the Rhine Basin’, *Water Resources Management*, 22(11), pp. 1677–1708.

Khajeh-Hosseini, A., Greenwood, D., Smith, J. W. and Sommerville, I. (2010) *The cloud adoption toolkit: Addressing the challenges of cloud adoption in enterprise*, *Cornel University Library*. Available at: http://arxiv.org/abs/1003.3866.

Khansa, L. and Zobel, C. W. (2014) ‘Assessing innovations in cloud security’, *Journal of Computer Information Systems*, 54(3), pp. 45–56.

Kloprogge, P., Van der Sluijs, J. P. and Petersen, A. C. (2011) ‘A method for the analysis of assumptions in model-based environmental assessments’, *Environmental Modelling and Software*, 26(3), pp. 289–301.

Knight, F. H. (1921) *Risk, uncertainty and profit*. Washington DC: BeardBooks.

Koh, S. C. L. and Saad, S. M. (2006) ‘Managing uncertainty in ERP-controlled manufacturing environments in SMEs’, *International Journal of Production Economics*, 101(1 SPEC. ISS.), pp. 109–127.

Kutsch, E. and Hall, M. (2005) ‘Intervening conditions on the management of project risk: Dealing with uncertainty in information technology projects’, *International Journal of Project Management*, 23(8), pp. 591–599.

Laili, Y., Tao, F., Zhang, L. and Sarker, B. R. (2012) ‘A study of optimal allocation of computing resources in cloud manufacturing systems’, *International Journal of Advanced Manufacturing Technology*, 63(5-8), pp. 671–690.

Leach, A. W., Levontin, P., Holt, J., Kell, L. T. and Mumford, J. D. (2014) ‘Identification and prioritization of uncertainties for management of Eastern Atlantic bluefin tuna (Thunnus thynnus)’, *Marine Policy*, 48, pp. 84–92.

Li, W. and Mehnen, J. (eds) (2013) *Cloud Manufacturing: Distributed Computing Technologies for Global and Sustainable Manufacturing*. 1st edn. London: Springer.

Li, Y., Chen, J. and Feng, L. (2013) ‘Dealing with uncertainty: A survey of theories and practices’, *IEEE Transactions on Knowledge and Data Engineering*, 25(11), pp. 2463–2482.

Løken, E. (2007) 'Use of multicriteria decision analysis methods for energy planning problems', *Renewable and Sustainable Energy Reviews*, 11(7), pp. 1584–1595.

Luo, Y., Zhang, L., Tao, F., Ren, L., Liu, Y. and Zhang, Z. (2013) 'A modeling and description method of multidimensional information for manufacturing capability in cloud manufacturing system', *International Journal of Advanced Manufacturing Technology*, 69(5-8), pp. 961–975.

Lv, B. (2012) 'A Multi-view Model Study for the Architecture of Cloud Manufacturing', in *Proceedings of 2012 Third International Conference onDigital Manufacturing and Automation (ICDMA), Shenyang, China*, pp. 93–97.

Mamdani, E. H. and Assilian, S. (1975) 'An experiment in linguistic synthesis with a fuzzy logic controller', *International Journal of Man-Machine Studies*, 7(1), pp. 1–13.

ManuCloud (2010) Project Overview, ManuCloud. Available at: http://www.manucloud-project.eu (Accessed: 25 March 2013).

Marshall, C. and Rossman, G. B. (2010) *Designing qualitative research*. 5th edn. UK: Sage publications.

Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J. and Ghalsasi, A. (2011) 'Cloud computing - The business perspective', *Decision Support Systems*, 51(1), pp. 176–189.

Marzouk, M. and Elmesteckawi, L. (2015) 'Analyzing procurement route selection for electric power plants projects using SMART', *Journal of Civil Engineering and Management*, 21(7), pp. 912–922.

Mell, P. and Grance, T. (2011) 'The NIST definition of cloud computing'. NIST Special Publication. National Institute of Standards and Technology.

MFG.com (2013) *About MFG.com*. Available at: http://www.mfg.com/about-mfgcom (Accessed: 18 June 2013).

Misra, S. C. and Mondal, A. (2011) 'Identification of a company's suitability for the adoption of cloud computing and modelling its corresponding Return on Investment', *Mathematical and Computer Modelling*, 53(3-4), pp. 504–521.

Mourtzis, D., Doukas, M. and Psarommatis, F. (2013) 'Design and operation of manufacturing networks for mass customisation', *CIRP Annals - Manufacturing Technology*, 62(1), pp. 467–470.

Myllyviita, T., Leskinen, P. and Seppälä, J. (2014) 'Impact of normalisation, elicitation technique and background information on panel weighting results in life cycle assessment', *International Journal of Life Cycle Assessment*, 19(2), pp. 377–386.

Negnevitsky, M. (2011) *Artificial Intelligence: A Guide to Intelligent Systems*. 3rd edn. England: Addison Wesley.

NIST (2004) *FIPS PUB 199: Standards for Security Categorization of Federal Information and Information Systems*. Gaithersburg, USA: National Institute of Standards and Technology (NIST).

Ogunde, N., A. and Mahnen, J. (2013) 'Factors Affecting Cloud Technology Adoption: Potential User's Perspective', in Li, W. and Mahnen, J. (ed.) *Cloud Manufacturing*. 1st edn. London: Springer, pp. 77–89.

Olsson, R. (2007) 'In search of opportunity management: Is the risk management process enough?', *International Journal of Project Management*, 25(8), pp. 745–752.

Oughton, D. H., Agüero, A., Avila, R., Brown, J. E., Copplestone, D. and Gilek, M. (2008) 'Addressing uncertainties in the ERICA Integrated Approach', *Journal of Environmental Radioactivity*, 99(9), pp. 1384–1392.

Panchal, J. H. and Schaefer, D. (2007) 'Towards achieving agility in web-based virtual enterprises: a decision-centric approach', *International Journal of Internet Manufacturing and Services*, 1(1), pp. 51–74.

PhotoBox (2013) *About Us, PhotoBox*. Available at: http://www.photobox.co.uk/content/about-us (Accessed: 18 June 2013).

Pring, B., Brown, R.H., Leong, L., Biscotti, F., Couture, A.W., Lheureux, B.J., Frank, A., Roster, J., Cournoyer, S. and Liu, V. K. (2010) *Forecast: Public cloud services, worldwide and regions, industry sectors, 2009-2014*. Gartner Report.

Project Management Institute (2013) *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*. USA: Project Management Institute.

Quirky (2013) *Help How It Works, Quirky*. Available at: http://www.quirky.com/how-it-works (Accessed: 18 June 2013).

Raftery, J. (2003) *Risk analysis in project management*. 2nd edn. London: Taylorand Francis.

Refsgaard, J. C., van der Sluijs, J. P., Højberg, A. L. and Vanrolleghem, P. A. (2007) 'Uncertainty in the environmental modelling process - A framework and guidance', *Environmental Modelling and Software*, 22(11), pp. 1543–1556.

Ren, L., Zhang, L., Wang, L., Tao, F. and Chai, X. (2014) 'Cloud manufacturing: key characteristics and applications', *International Journal of Computer Integrated Manufacturing*, pp. 1–15. Available at: http://dx.doi.org/10.1080/0951192X.2014.902105 (Accessed: 28 May 2014).

Research on Key Technologies of Cloud Manufacturing Service Platform (2011) Introduction, Cloud Manufacturing. Available at: http://en.cloudmfg.org/Default.aspx (Accessed: 20 April 2013).

Riza, L. S., Bergmeir, C., Herrera, F. and Benítez, J. M. (2015) 'frbs: Fuzzy rule-based systems for classication and regression in R', *Journal of Statistical Software*, 65(6), pp. 1–30.

Robson, C. (2015) *Real world research*. 4th edn. UK: John Wiley and Sons.

Rodríguez, A., Ortega, F. and Concepción, R. (2016) ‘A method for the evaluation of risk in IT projects’, *Expert Systems with Applications*, 45, pp. 273–285.

Ross, T. J., Booker, J. M. and Montoya, A. C. (2013) ‘New developments in uncertainty assessment and uncertainty management’, *Expert Systems with Applications*, 40(3), pp. 964–974.

Roy, S. K., Sarkar, A. K. and Mahanty, B. (2016) ‘Fuzzy risk assessment for electro-optical target tracker’, *International Journal of Quality and Reliability Management*, 33(6), pp. 830–851.

Ryan, J. J. C. H., Mazzuchi, T. A., Ryan, D. J., Lopez De La Cruz, J. and Cooke, R. (2012) ‘Quantifying information security risks using expert judgment elicitation’, *Computers and Operations Research*, 39(4), pp. 774–784.

Saaty, T. L. (1990) ‘How to make a decision: The analytic hierarchy process’, *European Journal of Operational Research*, 48(1), pp. 9–26.

Saltelli, A. (2008) *Global Sensitivity Analysis: The Primer*. 1st edn. John Wiley and Sons.

Samson, S., Reneke, J. A. and Wiecek, M. M. (2009) ‘A review of different perspectives on uncertainty and risk and an alternative modeling paradigm’, *Reliability Engineering and System Safety*, 94(2), pp. 558–567.

Sani, S. M., Aris, T. N. M., Mustapha, N. and Sulaiman, M. N. (2015) ‘A fuzzy logic approach to manage uncertainty and improve the prediction accuracy in student model design’, *Journal of Theoretical and Applied Information Technology*, 82(3), pp. 366–377.

Saunders, M., Thornhill, A. and Lewis, P. (2009) *Research Methods for Business Students*. 5th edn. Harlow, England: Pearson Education.

Schwabe, O., Shehab, E. and Erkoyuncu, J. (2015) 'Uncertainty quantification metrics for whole product life cycle cost estimates in aerospace innovation', *Progress in Aerospace Sciences*, 77, pp. 1–24.

Shade O, K., Frank, I. and Oludele, A. (2011) 'Cloud computing security issues and challenges', *International Journal of Computer Networks*, 3(5), pp. 247–255.

Shapeways (2013) *About Us, Shapeways*. Available at: http://www.shapeways.com/about?li=footer# (Accessed: 22 June 2013).

Simoen, E., De Roeck, G. and Lombaert, G. (2015) 'Dealing with uncertainty in model updating for damage assessment: A review', *Mechanical Systems and Signal Processing*, 56, pp. 123–149.

Singh, H., Gupta, M. and Meitzler, T. (2013) 'Real-life applications of fuzzy logic', *Advances in Fuzzy Systems*, 2013, pp. 581879–1.

Skinner, D. J. C., Pollard, S. J. T., Rocks, S. a. and Drew, G. H. (2014) 'Identifying Uncertainty in Environmental Risk Assessments: The Development of a Novel Typology and Its Implications for Risk Characterization', *Human and Ecological Risk Assessment: An International Journal*, 20(3), pp. 607–640.

van der Sluijs, J. P., Craye, M., Funtowicz, M., Kloprogge, P., Ravetz, J. and Risbey, J. (2005) 'Combining quantitative and qualitative measures of uncertainty in model-based environmental assessment: the {NUSAP} system', *Risk Analysis*, 25(2), pp. 481–492.

Soroudi, A. and Amraee, T. (2013) 'Decision making under uncertainty in energy systems: State of the art', *Renewable and Sustainable Energy Reviews*, 28, pp. 376–384.

Subramanian, N. and Ramanathan, R. (2012) 'A review of applications of Analytic Hierarchy Process in operations management', *International Journal of Production Economics*, 138(2), pp. 215–241.

Sudha, S. a. and Viswanatham, V. (2013) ‘Addressing security and privacy issues in cloud computing’, *Journal of Theoretical and Applied Information Technology*, 48(2), pp. 708–719.

Tao, F., Zhang, L. and Nee, A. Y. C. (2011a) ‘A review of the application of grid technology in manufacturing’, *International Journal of Production Research*, 49(13), pp. 4119–4155.

Tao, F., Zhang, L., Venkatesh, V. C., Luo, Y. and Cheng, Y. (2011b) ‘Cloud manufacturing: a computing and service-oriented manufacturing model’, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 225(April 2016), pp. 1969–1976.

Tao, F., Zhao, D., Yefa, H. and Zhou, Z. (2010) ‘Correlation-aware resource service composition and optimal-selection in manufacturing grid’, *European Journal of Operational Research*, 201(1), pp. 129–143.

Tobergte, D. R. and Curtis, S. (2013) ‘Unleashing the Potential of Cloud Computing in Europe’, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions*. European Commission.

Udovyk, O. and Gilek, M. (2013) ‘Coping with uncertainties in science-based advice informing environmental management of the Baltic Sea’, *Environmental Science and Policy*, 29, pp. 12–23.

Uusitalo, L., Lehikoinen, A., Helle, I. and Myrberg, K. (2015) ‘An overview of methods to evaluate uncertainty of deterministic models in decision support’, *Environmental Modelling and Software*, 63, pp. 24–31.

Valilai, O. F. and Houshmand, M. (2013) ‘A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm’, *Robotics and Computer-Integrated Manufacturing*, 29(1), pp. 110–127.

Voorsluys, W., Broberg, J. and Buyya, R. (2011) 'Introduction to Cloud Computing', in Buyya, R., Broberg, J. and Goscinski, A. (ed.) *Cloud Computing: Principles and Paradigms*. 1st edn. New Jersey, USA: John Wiley and Sons.

Walker, W.E., Harremoës, P., Rotmans, J., van der Sluijs, J.P., van Asselt, M.B., Janssen, P. and Krayer von Krauss, M. P. (2003) 'Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support', *Integrated assessment*, 4(1), pp. 5–17.

Wang, L. (2013) 'Machine availability monitoring and machining process planning towards Cloud manufacturing', *CIRP Journal of Manufacturing Science and Technology*, 6(4), pp. 263–273.

Wang, L., Laszewski, G. V, Kunze, M., Tao, J. and Dayal, J. (2010) 'Provide Virtual Distributed Environments for Grid computing on demand', *Advances in Engineering Software*, 41(2), pp. 213–219.

Wang, S., Chen, G., Kang, L. and Li, Q. (2012) 'Information model of cloud manufacturing resource based on semantic web', *International Journal of Digital Content Technology and its Applications*, 6(19), pp. 339–346.

Wang, S. L., Guo, L., Kang, L., Li, C. S., Li, X. Y. and Stephane, Y. M. (2014) 'Research on selection strategy of machining equipment in cloud manufacturing', *International Journal of Advanced Manufacturing Technology*, 71(9-12), pp. 1549–1563.

Wang, X. V. and Xu, X. W. (2013) 'An interoperable solution for Cloud manufacturing', *Robotics and Computer-Integrated Manufacturing*, 29(4), pp. 232–247.

Ward, S. and Chapman, C. (2003) 'Transforming project risk management into project uncertainty management', *International Journal of Project Management*, 21(2), pp. 97–105.

Wiendahl, H.-P. and Lutz, S. (2002) 'Production in networks', *CIRP Annals-Manufacturing Technology*, 51(2), pp. 573–586.

Wu, D., Greer, M. J., Rosen, D. W. and Schaefer, D. (2013) ‘Cloud manufacturing: Strategic vision and state-of-the-art’, *Journal of Manufacturing Systems*, 32(4), pp. 564–579.

Wyld, D. C. (2009) ‘Moving to the Cloud : An Introduction to Cloud Computing in Government’. IBM Center for the Business of Government.

Xu, X. (2012) ‘From cloud computing to cloud manufacturing’, *Robotics and Computer-Integrated Manufacturing*, 28(1), pp. 75–86.

Yadekar, Y., Shehab, E. and Mehnen, J. (2013) ‘Challenges of Cloud Technology in Manufacturing Environment’, in *Proceedings of the 11th International Conference on Manufacturing Research (ICMR2013)*. Cranfield, UK, 19–20 September 2013, pp. 177–182.

Yadekar, Y., Shehab, E. and Mehnen, J. (2014a) ‘A Taxonomy for Cloud Manufacturing’, in *Proceedings of the 12th International Conference on Manufacturing Research (ICMR2014)*. Southampton UK, 9-11 September 2014, pp. 103–108.

Yadekar, Y., Shehab, E. and Mehnen, J. (2014b) ‘Uncertainties in Cloud Manufacturing’, in *Proceedings of the 21st ISPE Inc. International Conference on Concurrent Engineering*. China, pp. 297–306.

Yadekar, Y., Shehab, E. and Mehnen, J. (2015) ‘An approch to assess uncertainties in cloud manufacturing’, in *In Transdisciplinary Lifecycle Analysis of Systems: Proceedings of The 22nd ISPE Conference on Concurrent Engineering*. Delft, Netherlands, pp. 318–324.

Yadekar, Y., Shehab, E. and Mehnen, J. (2016) ‘Taxonomy and uncertainties of cloud manufacturing’, *International Journal of Agile Systems and Management*, 9(1), pp. 48–66.

Yan, J., Xin, S., Liu, Q. and Xu, W. (2013) ‘Capability Service Management System for Manufacturing Equipments in Cloud Manufacturing’, *Advances in Information Sciences and Service Sciences*, 5(5), pp. 677–685.

Yang, N., Li, D. and Tong, Y. (2012) ‘A cloud computing-based ERP system under the cloud manufacturing environment’, *International Journal of Digital Content Technology and its Applications*, 6(23), pp. 126–134.

Yera, R., Castro, J. and Martínez, L. (2016) ‘A fuzzy model for managing natural noise in recommender systems’, *Applied Soft Computing Journal*, 40, pp. 187–198.

Yin, R. K. (2013) *Case study research: Design and methods*. 5th edn. UK: Sage publications.

Yusuf, Y. Y., Sarhadi, M. and Gunasekaran, A. (1999) ‘Agile manufacturing: The drivers, concepts and attributes’, *International Journal of Production Economics*, 62(1), pp. 33–43.

Zadeh, L. A. (1965) ‘Fuzzy sets’, *Information and Control*, 8(3), pp. 338–353.

Zafar, H., Ko, M. S. and Osei-Bryson, K. M. (2015) ‘The value of the CIO in the top management team on performance in the case of information security breaches’, *Information Systems Frontiers*, p. pp 1–11. Available at: http://link.springer.com/article/10.1007/s10796-015-9562-5 (Accessed: 19 August 2015).

Zavadskas, E. K., Turskis, Z. and Kildiene, S. (2014) ‘State of art surveys of overviews on MCDM/MADM methods’, *Technological and Economic Development of Economy*, 20(1), pp. 165–179.

Zhang, L., Luo, Y., Tao, F., Li, B. H., Ren, L., Zhang, X., Guo, H., Cheng, Y., Hu, A. and Liu, Y. (2014) ‘Cloud manufacturing: a new manufacturing paradigm’, *Enterprise Information Systems*, 8(2), pp. 167–187.

Zhang, Q., Cheng, L. and Boutaba, R. (2010) ‘Cloud computing: state-of-the-art and research challenges’, *Journal of internet services and applications*, 1(1), pp. 7–18.

Zhang, Y. and Jin, Y. (2012) ‘Research on knowledge management for group enterprise in cloud manufacturing’, in *Proceedings of 2012 International Conference on Computer Science and Service System, CSSS 2012*. Nanjing; China, 11-13 August 2012, pp. 1946–1950.

APPENDICES

Appendix A Publications

A.1 A Framework to Manage Uncertainties in Cloud Manufacturing (To be submitted)

Int. J. Production Economics xx

A FRAMEWORK TO MANAGE UNCERTAINTIES IN CLOUD MANUFACTURING

Yaser Yadekar, Essam Shehab, Jörn Mehnen

School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, UK

ABSTRACT

A new manufacturing paradigm has emerged, called Cloud Manufacturing. This new paradigm has the ability to provide services-oriented manufacturing that provides both physical products and services together. However, Cloud Manufacturing needs to deal with the uncertainties that influence system performance. This research paper proposes a framework to manage uncertainty in Cloud Manufacturing. The framework provides an approach to evaluate the importance of uncertainties in Cloud Manufacturing by using the Simple Multi-Attribute Rating Technique (SMART) to prioritise uncertainties that exist in Cloud Manufacturing. Additionally, an online assessment tool has been developed to help decision makers identify uncertainties and prioritise them in Cloud Manufacturing.

Keywords: Cloud Manufacturing, Cloud Computing, Uncertainty, Uncertainty Framework, Simple Multi-Attribute Rating Technique

1 INTRODUCTION

Technology plays an ever more important role in linking enterprises and markets. The development of new technologies has helped enterprises to support their decision-making processes; to gain competitive advantage; and to enter new markets globally. New technologies such as Cloud Computing, Internet of Things, Virtualization, and Web Services, with the support of existing advanced manufacturing networks has the ability to change and restructure manufacturing systems in the manufacturing industry (Xu, 2012). However, the manufacturing industry is facing many problems with existing manufacturing networks that affect the whole life cycle of the manufacturing process. Those problems include: manufacturing resources sharing, accessibility of equipment, and knowledge sharing (Laili *et al.*, 2012; Xu, 2012; Gao *et al.*, 2013; Valilai and Houshmand, 2013).

A.2 Uncertainty Quantification in Cloud Manufacturing (To be submitted)

Robotics and Computer-Integrated Manufacturing xx

UNCERTAINTY QUANTIFICATION IN CLOUD MANUFACTURING

Yaser Yadekar, Essam Shehab, Jörn Mehnen

School of Aerospace, Transport and Manufacturing, Cranfield University, Cranfield, UK

Abstract

With Information Technology revolutionary in manufacturing industry, uncertainty assessment is becoming an important tool to understand and manage uncertainties. It's predicted future outcomes and behaviours in Cloud Manufacturing, as well as allows stakeholders to make better decisions. This paper proposes a systematic process to quantify security and privacy uncertainties in terms of confidentiality, integrity, and availability of Cloud Manufacturing. The developed system employed rule-based Mamdani-type fuzzy modelling to determine how the outcomes of Cloud Manufacturing in the present of uncertainties.

Keywords: Cloud Manufacturing, Cloud Computing, Uncertainty, Fuzzy rule-based system

1 INTRODUCTION

Over the past years, the implementation of new technologies and complex networks in enterprises has created uncertain outcomes and unpredictable situations, known as "uncertainties". The higher existence of uncertainties in problem leads to less understanding of this problem (Booker and Ross, 2011). Due the nature of uncertainty that comes from gaps in knowledge (Epistemic uncertainty), or results natural variability because of the physical environment (Aleatory uncertainty), it is hard to get rid of uncertainties totally, but being aware of them means they can be dealt with (Li *et al.*, 2013).

Decision makers need to characterise and quantify uncertainties in a systematic process in order to determine the outcomes of a model (system) in the presence of uncertainties; this process known as uncertainty quantification.

A.3 Taxonomy and uncertainties of cloud manufacturing (2016)

48 *Int. J. Agile Systems and Management, Vol. 9, No. 1, 2016*

Taxonomy and uncertainties of cloud manufacturing

Yaser Yadekar, Essam Shehab* and
Jörn Mehnen

Manufacturing Department,
School of Aerospace, Transport and Manufacturing,
Cranfield University,
Cranfield, Bedfordshire, MK43 0AL, UK
Email: y.m.yadekar@cranfield.ac.uk
Email: e.shehab@cranfield.ac.uk
Email: j.mehnen@cranfield.ac.uk
*Corresponding author

Abstract: The manufacturing industry is currently undergoing rapid changes because of the rapid growth of advanced technologies in information systems and networks, which allow for collaboration around the world. This combination of the latest information technologies and advanced manufacturing networks has led to the growth of a new manufacturing model known as cloud manufacturing. Because cloud manufacturing is considered an emerging research area, there are significant gaps in the literature regarding the concept of cloud manufacturing, its implementation, and in particular the uncertainties coming with this new technology. This research aims to explain the concept of cloud manufacturing, its capabilities and potential. This work also introduces cloud manufacturing taxonomy, and investigates uncertainties that come with employing cloud manufacturing. Finally, proposals for future research in the context of cloud manufacturing are presented to address opportunities in cloud manufacturing.

Keywords: cloud manufacturing; taxonomy; uncertainty.

Reference to this paper should be made as follows: Yadekar, Y., Shehab, E. and Mehnen, J. (2016) 'Taxonomy and uncertainties of cloud manufacturing', *Int. J. Agile Systems and Management*, Vol. 9, No. 1, pp.48–66.

Biographical notes: Yaser Yadekar is a PhD student at School of Aerospace, Transport and Manufacturing, Cranfield, Cranfield University. He holds an MSc in Technology Management (specialising in Information Systems) and a Bachelor degree in Statistic (minor in Management Information Systems). His research interests are cloud manufacturing, cloud computing, fuzzy modelling, and uncertainty.

Essam Shehab is a Reader and leads a research group in product and service engineering at Cranfield University. He has successfully completed the supervision of 20 PhD theses, five MSc by research theses and 85 MSc theses. He has developed a strong track record of applied research with leading industrial companies including Airbus, Rolls-Royce and BAE Systems. He has published extensively in his research career with 200 research publications. He is a Fellow of IET, ACostE and the Higher Education Academy (HEA).

A.4 An Approach to Assess Uncertainties in Cloud Manufacturing (2015)

Transdisciplinary Lifecycle Analysis of Systems
R. Curran et al. (Eds.)

doi:10.3233/978-1-61499-544-9-318

An Approach to Assess Uncertainties in Cloud Manufacturing

Yaser Yadekar, Essam Shehab[1] and Jorn Mehnen
Manufacturing Department, Cranfield University, UK

Abstract. As new technologies and advanced networks play an increasing important role in manufacturing, many enterprises are suffering from unknown and unpredictable situations, termed "uncertainties". The aim of this paper is to provide an approach to evaluate the importance of uncertainties in Cloud Manufacturing. The Simple Multi-Attribute Rating Technique (SMART) was used in this research to assess uncertainties that exist in Cloud Manufacturing. Additionally, a Microsoft Excel assessment tool has been developed to help decision makers identify uncertainties and determine the weight of uncertainty in Cloud Manufacturing.

Keywords. Cloud Manufacturing, Uncertainties, Simple Multi-Attribute Rating Technique (SMART)

Introduction

Technology plays an ever more important role in linking enterprises and markets. The development of new technologies has helped enterprises to support their decision-making processes; to gain competitive advantage; and to enter new markets globally. New technologies such as Cloud Computing, Internet of Things, Virtualization, and Web Services, with the support of existing advanced manufacturing networks has the ability to change and restructure manufacturing systems in the manufacturing industry [1]. However, the manufacturing industry is facing many problems with existing manufacturing networks that affect the whole life cycle of the manufacturing process. Those problems include: manufacturing resources sharing, accessibility of equipment, and knowledge sharing [1,2,3,4].

With the emergence of new technologies, a new manufacturing paradigm, called "Cloud Manufacturing", has arisen and received attention from both researchers and professionals over the past few years [5]. This paradigm allows: sharing of manufacturing resources, capabilities, and knowledge between different parties (manufacturing units, suppliers, other enterprises and customers) [6]; reduction in costs, and maximization of productivity, business agility and innovation [7].

Appling new and complex technologies and networks in enterprises can create unknown and unpredictable situations, known as "uncertainties". Every enterprise tries to avoid, at any cost, having the undesirable state of 'uncertainty' in their system, as more uncertainty in a problem can lead to less understanding of that problem [8].

[1] Corresponding author; E-mail: e.shehab @cranfield.ac.uk

A.5 Uncertainties in Cloud Manufacturing (2014)

Moving Integrated Product Development to Service Clouds in the Global Economy 297
J. Cha et al. (Eds.)

doi:10.3233/978-1-61499-440-4-297

Uncertainties in Cloud Manufacturing

Yaser YADEKAR [a], Essam SHEHAB [a,1] and Jorn MEHNEN [a]
[a] *Manufacturing and Materials Department, Cranfield University, UK*

Abstract. The use of new technologies in information systems and advanced networks has allowed the manufacturing industry to apply new, complex manufacturing systems based on advanced networks and new computing technologies. Cloud Manufacturing, as a new paradigm, is continuously gaining attention by academics and industry. However, there is still a lack of understanding of the concept of Cloud Manufacturing, its implementation and – in particular – the uncertainties coming with this new technology. This paper focuses on defining and evaluating uncertainties in Cloud Manufacturing, provides a list of identified uncertainties and proposes uncertainty management for Cloud Manufacturing.

Keywords. Cloud Manufacturing, Cloud Computing, Uncertainties

Introduction

The use of new technologies and networks are becoming critical success factors in any business enterprise. Enterprises are trying to gain a competitive advantage in global markets by using the latest technologies, along with networks, to create collaboration. Currently, enterprises rely on many advanced network technologies, such as Agile Manufacturing (AM), Network Manufacturing (NM), and Manufacturing Grid (MG) to operate a single manufacturing task from the integration of widely distributed sources [1]. These manufacturing networks enable collaboration and sharing of manufacturing resources between manufacturing units.

Today, manufacturing industry is facing problems in these existing network technologies that affect production within the manufacturing industry. These problems include: the sharing of manufacturing resources, where the resources are centralized into the network but cannot be distributed through the network due to lack of manufacturing service management in the network; and the inability to access the manufacturing hard resources (equipment) in the manufacturing network due to complications in transferring hard resources into the network [1,2,3].

Another problem is the difficulty of knowledge sharing between manufacturing units, suppliers, customers, and partners due to geographical dimension, countries' regulations, different operation systems, and amount of data and complex processes in manufacturing [4]. The sharing of knowledge can provide development strategies in how to both enhance competitive advantage and understand manufacturing practices within the industry [5].

[1] Essam Shehab, Manufacturing and Materials Department, Cranfield University, UK; E-mail: e.shehab @cranfield.ac.uk

A.6 A Taxonomy for Cloud Manufacturing (2014)

Proceedings of the 12th International Conference on Manufacturing Research (ICMR2014)

A TAXONOMY FOR CLOUD MANUFACTURING

Yaser Yadekar
Manufacturing and Materials Department
Cranfield University
Cranfield
Bedford, MK43 0AL, UK
y.m.yadekar@cranfield.ac.uk

Essam Shehab
Manufacturing and Materials Department
Cranfield University
Cranfield
Bedford, MK43 0AL, UK
e.shehab@cranfield.ac.uk

Jörn Mehnen
Manufacturing and Materials Department
Cranfield University
Cranfield
Bedford, MK43 0AL
j.mehnen@cranfield.ac.uk

ABSTRACT

Cloud Manufacturing is one of the emerging technologies in the field of Information Technology. However, the literature shows that there are huge gaps in research related to Cloud Manufacturing. The research gap identified include: lack of understanding of the Cloud Manufacturing concept. The majority of scholars concentrate only on Cloud Manufacturing system architecture and the enabling technologies. There are also lacks of understanding of the stakeholders interactions and their activities in a Cloud Manufacturing system. This paper attempts to identify and capture requirements for Cloud Manufacturing and its types, characteristics and attributes by providing a Cloud Manufacturing taxonomy.

Keywords: Taxonomy, Cloud Manufacturing, Cloud Computing

1 INTRODUCTION

The manufacturing industry is currently undergoing rapid changes because of the rapid growth of advanced technologies in information systems and networks, which allow for collaboration around the world. There is an ever increasing demand to provide service-oriented manufacturing (Xu 2012), to distribute manufacturing resources and capabilities, and increase productivity. The role of technology in the manufacturing industry has become a critical factor and it is fundamental in supporting technical and business progress in the enterprise (Yadekar *et al.* 2013).

Today, the emergence of new technologies such as Cloud Computing, Internet of Things, Virtualization, and Web Services, with the help of existing advanced manufacturing networks, can shift the manufacturing industry from production-oriented manufacturing to services-oriented manufacturing. The combination of innovative technologies and existing manufacturing networks has created a new concept, called "Cloud Manufacturing" (Li and Mehnen 2013). The Cloud Manufacturing model is complex and involves many advanced technologies and networks that need to be integrated efficiently, and it provides the ability to exchange data and share knowledge among the different users (customer, suppliers, and partners) (Yadekar et al. 2013). In addition, it can be an important factor to reduce costs, maximize productivity, increase the utilization rate of resources and create collaboration (Wang and Xu 2013).

Cloud Manufacturing can be defined as "A customer-centric manufacturing model that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resource loading in response to variable-demand

A.7 Challenges of Cloud Technology in Manufacturing Environment (2013)

Proceedings of the 11[th] International Conference on Manufacturing Research (ICMR2013)

CHALLENGES OF CLOUD TECHNOLOGY IN MANUFACTURING ENVIRONMENT

Yaser Yadekar
Manufacturing and Materials Department
Cranfield University
Cranfield
Bedford, MK43 0AL, UK
y.m.yadekar@cranfield.ac.uk

Essam Shehab
Manufacturing and Materials Department
Cranfield University
Cranfield
Bedford, MK43 0AL, UK
e.shehab@cranfield.ac.uk

Jorn Mehnen
Manufacturing and Materials Department
Cranfield University
Cranfield
Bedford, MK43 0AL
j.mehnen@cranfield.ac.uk

ABSTRACT

The rapid growth Information systems and advanced network technologies have significant impact on enterprises around the world. Enterprises are trying to gain competitive advantage in open global markets by using the latest technologies, along with advanced networks, to create collaboration, reduce costs, and maximize productivity. The combination of latest technologies and advanced manufacturing networks technologies lead to growth of new manufacturing model named Cloud Manufacturing which can shift the manufacturing industry from product-oriented manufacturing to services-oriented manufacturing. This paper explores the literature about the current Manufacturing problems, understands the concept of Cloud Computing Technology, introduces Cloud Manufacturing and its role in the enterprise, and investigates the obstacles and challenges of adopting Cloud Manufacturing in enterprises.

Keywords: Cloud Technology, Cloud Manufacturing, and Cloud Computing.

1 INTRODUCTION

The use of new technologies and networks are becoming critical success factors in any enterprise. Enterprises are trying to gain competitive advantage in global markets by using the latest technologies, along with advanced networks, to create collaboration. Manufacturing companies currently rely on many advanced network technologies, such as Agile Manufacturing, Network Manufacturing, and Manufacturing Grid to operate a single manufacturing task from the integration of distributed sources. These manufacturing networks enable collaboration and sharing of manufacturing resources between manufacturing units (Xu 2012).

Although manufacturers benefit from the implementation of state-of-the-art technologies in gaining advantage over competitors, there are problems in these existing network technologies that affect production within the manufacturing industry. These issues include the sharing of manufacturing resources, where the manufacturing resources cannot be distributed into the manufacturing network due to lack of manufacturing services management in the manufacturing network. Inability accesses the manufacturing hard resources (i.e. equipments) in the manufacturing network (Gao *et. al* 2013). Absence of knowledge sharing and distribution between manufacturing units, suppliers, customers, and partners to development strategies in how to enhance competitive advantage and in how to understand manufacturing practices within the industry (Xu 2012).

To address the issues affecting the industry, a new manufacturing model, called Cloud Manufacturing, is emerging. This model can provide and share manufacturing resources and

Appendix B Questionnaires

B.1 Cloud Manufacturing Industrial Awareness Questionnaire

Dear,

I would like to invite you to participate in an online survey. This questionnaire is being conducted as part of PhD research project at Cranfield University, UK. The aim of this questionnaire is to measure the awareness of Cloud Computing Technology.

The questionnaire will take less than 10 minutes to complete. All responses will be treated as confidential and anonymised to protect your identity in any published data. I will be grateful for your assistance in helping me completing this survey.

Yaser Yadekar
E: y.m.yadekar@cranfield.ac.uk

If you would like to receive the result of this survey, please complete your details.

Name: ______________________________ Email: __________________

About you & your organisation

13. How many employees are working in your organisation?

☐ Less than 10 employees
☐ Less than 50 employees
☐ Less than 250 employees
☐ More than 250 employees

14. In which industry sector does your organisation belong to?

☐Manufacturing ☐Healthcare ☐Communications ☐Trade
☐Research & Development ☐ Education ☐Financial Services
☐Other: ________________________

15. What is your role in your organisation:

Job Title

☐Management ______________________
☐IT specialist ______________________
☐Researcher ______________________
☐Other (please specify) ______________________

16. Years of experience ____ years

17. Are you familiar with “Cloud Manufacturing” concept?

☐ Yes
☐ No
☐Not sure

18. **If yes**, do you think that Cloud Manufacturing is a manufacturing model developed from existing advanced manufacturing and enterprise information technologies under the support of cloud computing, Internet of Things, virtualization, and advanced computing technologies.

☐ Yes
☐ No
☐Not sure

About using/adopting Cloud Technology

19. Are you:

☐Cloud Operators (manage & control cloud services)
☐Cloud Resource Provider (own and provide resources & capabilities)
☐Cloud User (customer that require access to resources & capabilities)
☐Researcher
☐Other: ____________________________

20. Is your organisation…?

☐Using Cloud technology
☐Considers adopting Cloud technology
☐Neither

If your answer is Neither, don’t answer the rest of questions.

21. What type of Cloud technology deployment model that your organisation is using/ considers adopting?

☐Public Cloud (offered services and infrastructure from off-site, third party service provider via the Internet)
☐Private Cloud (provides same services and infrastructure of public cloud for enterprise but managed internally within enterprise)
☐Hybrid Cloud (consists of two types of clouds, public cloud and private cloud)

☐Community Cloud (shared and used by several enterprises that have the same mutual interests and concerns)
☐Don't know

22. What type of data and application were moved/ are consider to be moved into the Cloud?

☐Non- critical data and application
☐Critical data and application
☐Both
☐Other (please specify) ______________________

23. Is your organisation using/ considering adopting Cloud technology for …

☐Computational Resources (Infrastructure, platform, software)
☐Manufacturing Resources & Capabilities (equipment, monitor control devices, materials, information systems, software, knowledge, transportations, design, production, simulation, etc)

24. What are the reasons for using/ considering adopting Cloud technology in your organisation? (you can choose more than one answer)

☐Reduce investment cost in IT
☐Ability to access shared resources from any device, anywhere, and anytime.
☐Pricing flexibility (paying only for service according to user's needs)
☐ Collaboration
☐Require new services
☐Scalability (easily grow of information system)
☐Other:

25. What are the most important challenges for using/ considering adopting Cloud technology in your organisation?

	Most important	Very important	Quite Important	Important	Least important
Security & privacy	☐	☐	☐	☐	☐
Interoperability	☐	☐	☐	☐	☐

System Integrity	☐	☐	☐	☐	☐
Scalability	☐	☐	☐	☐	☐
Lack of Standards	☐	☐	☐	☐	☐
Lack of Transparency	☐	☐	☐	☐	☐
Quality of Service	☐	☐	☐	☐	☐
Vender-Lock in	☐	☐	☐	☐	☐
Cost of migrate into cloud	☐	☐	☐	☐	☐
Other:					

B.2 Delphi Survey – Round 1

Survey about the Uncertainties involved in Cloud Manufacturing

Dear,

As an active researcher in Cloud Manufacturing research field, I would like to invite you to participate in an online survey. This survey is being conducted as part of PhD research project entitled “A Framework to Manage Uncertainty in Cloud Manufacturing” at Cranfield University, UK.

This survey is based on Delphi approach that composed of two rounds, where each round will distribute online on separate occasion. All responses will be treated as confidential and anonymised to protect your identity in any published data. I will be grateful for your assistance in helping me completing this survey.

Please access the questionnaire by clicking the following link:

Sincerely,

Yaser Yadekar

Researcher, School of Applied Sciences

Cranfield University

E: y.m.yadekar@cranfield.ac.uk

- Round 1 –

Introduction

The purpose of this questionnaire:
To elicit your views on key Uncertainties in Cloud Manufacturing.
Definitions:

Cloud Manufacturing: A computing and service-oriented manufacturing model developed from existing advanced manufacturing models (ASP, AM, NM, MGrid) enterprise information technologies under the support of cloud computing, Internet of Things (IoT), virtualization and service-oriented technologies, and advanced computing technologies.

Uncertainty: a state of having limited knowledge where it is impossible to exactly describe existing state or future outcome, more than one possible outcome.

Uncertainty Examples:

Scholars and published industrial reports have identified problems and challenges (Uncertainties) related to Cloud Computing and Cloud Manufacturing (note that the majority of the studies and reports focused on Cloud Computing). The following are some of identified Uncertainty types:

No	Uncertainty Type
1	Security: Password and key cracking, launching dynamic attack points, hosting m
2	Availability: network outage and system failures.
3	Transform manufacturing resources and capabilities into Cloud.
4	Interoperability: ability to work together with different information systems.
5	Privacy: Data control, Data Location, Data Disclosure, Data transition
6	Transparency: not reveal how it grants employees access to physical and virtual a
7	Vender-Lock in: inability of a customer to move their data and/or programs away computing service provider.
8	Bandwidth: raise the cost of using network communication.
9	SLA Design: understand responsibilities of each party in the Cloud.
10	Training existing IT staff for Cloud System

What you need to do?
Answer the following question:
What are the most important Uncertainty types in Cloud Manufacturing system/project?

Instructions for Completing the Questionnaire

1. Please list all possible Uncertainty types in the table below.
2. In selecting your Uncertainty type, you may use any of the Uncertainty types specified above or generate your own.
3. For each Uncertainty type, please provide one line description and brief explanation.
4. After you completed filling out the questionnaire, you should click on "save" button to finish the questionnaire.
5. After saved the questionnaire, please email the document to y.m.yadekar@cranfield.ac.uk

Note: While preparing your response, please refer to the definitions and explanations given in the introduction.

B.3 Delphi Survey – Round 2

Survey about the Uncertainties involved in Cloud Manufacturing
- Round 2 -

Introduction

After analysis responses from Round-1, a summarized table of Uncertainty types was created. For each Uncertainty type, a one-two line description and comments by participants were included.

What you need to do?
Need to consider revising your earlier input after reviewing the feedback of the other participants by:

1. Add/delete/modify to any Uncertainty type.
2. Confirm the consistency of Uncertainty types.

Instructions for Completing the Questionnaire

After you completed filling out the questionnaire, please click on "save" button to finish the questionnaire and email the document to y.m.yadekar@cranfield.ac.uk

No	Uncertainty Type	Description	Notes
1	Security	Hacking: password and key cracking, hosting malicious data, Network /Host /Application security.	
2	Insecure Cloud Services interfaces	Anonymous access and/or reusable tokens or passwords, clear-text authentication or transmission of content, inflexible access controls or improper authorizations, limited	

No	Uncertainty Type	Description	Notes
		monitoring and logging capabilities.	
3	Administrative Management	Administrative controls specifying who can perform data related operations such as creation, access, disclosure, transport, and destruction.	
4	System Integrity	Ability to partition access rights to each of stakeholders groups.	
5	Permission control	Permission to share manufacturing resources, different users access to different resources. Need a strategy to confirm the resource access to different levels of users.	
6	Encryption Levels	Need to determine encryption type for each: data type, process, etc.	
7	Intellectual property (IP) protection	Prevent hacking/fishing attempts from competition.	
8	Privacy (data)	Data control, Data Location, Data Disclosure, and Data transition. May create conflict with regulations and data privacy laws in company's country.	
9	Privacy	Trade secrets protection, intellectual property (IP) protection, personal privacy protection.	
10	Legal	Compliance with different rules that are different from country to country.	
11	Bandwidth	A lot of manufacturing resource real-time data will be collected to the server that results in huge demands on network bandwidth.	
12	Availability	Network outage and system failures OR Inability of access cloud services due to lack of network connectivity	
13	Interoperability (Design/Manuf.)	Ensure manufacturing service selected/requested matches requirements of design. Example: Certain design features may not come out right if inappropriate manufacturing equipment is chosen (resolution, materials, etc.)	

No	Uncertainty Type	Description	Notes
14	Manufacturing resource or service request is uncertain	Manufacturing resource or service requirements are dynamically changing. Where The requirements of manufacturing resource or service submitted to the cloud manufacturing platform is uncertain, including the type, number, functionality requirements, workflow requirement, etc.	

B.4 CIA model Questionnaire

Dear,

I would like to invite you to participate in an online survey. This questionnaire is being conducted as part of PhD research project at Cranfield University, UK. The aim of questionnaire is to select the most important uncertainty factors, according to the CIA model's components (Confidentiality–Integrity–Availability). The questionnaire will take less than 5 minutes to complete. All responses will be treated as confidential and anonymised to protect your identity in any published data.

Cranfield University

* If you would like to receive the result of this survey, please complete your details.

Name

Email

* What is your role in your organisation:

- Management
- Researcher
- IT specialist
- Other (please specify):

* Years of experience:

The Table show a detailed description of security factors in the Cloud.

No	Factor	Description
1	Data Breach or Loss	This factor is related to data breach from outside/inside users into the Cloud by hacking passwords and key cracking and hosting malicious data.
2	Data Control	This factor is related to loss of physical control over data.
3	Bandwidth Capacity	This factor is related to ability of collect real-time data from different resources to the server. This results in huge demands on network bandwidth capability.
4	Insecure Cloud Services interfaces	This factor is related to anonymous access and/or reusable tokens or passwords, clear-text authentication or transmission of content, inflexible access controls or improper authorizations, limited monitoring capabilities.
5	Applications Security	This factor is related to ability of protecting software applications from piracy, ip hacking, cloning security
6	Cloud Service Availability	This factor is related to network outage and system failures OR Inability of access Cloud services due to lack of network connectivity
7	Remotely access Cloud services security	This factor is related to remotely access Cloud services without effecting encryption/ decryption mechanism in the Cloud.
8	Hardware/Machine Availability	This factor is related to hardware/machine availability that multiple users are querying the same hardware/machine parallel.
9	Cloud Services interfaces data transmission Security	This factor is related to transmission clean error and message handling between Cloud services interfaces.

Q1) How much experience do you have with Cloud technology?

Very High	High	Low	Very Low	None
○	○	○	○	○

Q2) Is your organisation.....

- ○ Using Cloud technology
- ○ Considers adopting Cloud technology
- ○ Neither

Q3) Do you aware of Cloud Security problems/challenges/issues?

- ○ Yes
- ○ No

Q4) The three main components of Cloud security model are:

- Confidentiality: is the prevention of unauthorized disclosure of data.
- Integrity: ensures the protection of the data while in storage and transit.
- Availability: is the guarantee that data will be available to the users and data owners in a timely and uninterrupted manner when it is needed regardless of location of the user.

***Please, select the main factors likely to affect Cloud security for each component (Confidentiality-Integrity-Availability).**

	Confidentiality	Integrity	Availability	Not relevant
Data Breach or Loss	○	○	○	○
Data Control	○	○	○	○
Data Location	○	○	○	○
Bandwidth Capacity	○	○	○	○
Insecure Cloud Services interfaces	○	○	○	○
Applications Security	○	○	○	○
Cloud Service Availability	○	○	○	○
Remotely access Cloud services security	○	○	○	○
Hardware/Machine Availability	○	○	○	○
Cloud Services interfaces data transmission Security	○	○	○	○

>>

Survey Powered By Qualtrics

B.5 Taxonomy Validation Questionnaire

Dear,

As an expert in information technology field, I would like to invite you to participate in this survey. The aim of the questionnaire is to validate taxonomy of Cloud Manufacturing. This validation is part of PhD research project entitled "A Framework to Manage Uncertainty in Cloud Manufacturing" at Cranfield University, UK. I will be grateful for your assistance in helping me completing this questionnaire.

Instructions for Completing the Questionnaire:

1) Read the Cloud Manufacturing Taxonomy.
2) Answer questions in the questionnaire.
3) After you completed filling out the questionnaire, please click on "save" button to finish the questionnaire and email the document to y.m.yadekar@cranfield.ac.uk

Sincerely,

Yaser Yadekar

Survey to validate Cloud Manufacturing taxonomy

Name: ______________________________

Job Title: ____________________________

Years of Experience: ___________________

Knowledge in: ☐Cloud Computing ☐ Manufacturing ☐ Others:

Definition:-

Cloud Manufacturing: is a manufacturing model developed from existing advanced manufacturing and enterprise information technologies under the support of cloud computing, Internet of Things, virtualization, and advanced computing technologies.

Questions:

1. Would the taxonomy be useful for researchers and for enterprises that using or considering adopting Cloud Manufacturing?

2. Are the concepts and terminology in the taxonomy well explained and easy to understand?

3. What are the limitations of the taxonomy?

4. What improvements are needed for the taxonomy?

B.6 Tool Verification Questionnaire

Name

Email

Job Title

* Years of experience:

Q1) The tool's Interface is well designed, easy to understand and operate.

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

Q2) The information and instructions easy to understand and follow.

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

Q3) The tool is easy to navigate between pages

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

Q4) The tool is bug free.

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

Q5) The tool's performance is satisfied.

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

Other remarks

Submit

Survey Powered By Qualtrics

B.7 Tool Validation Questionnaire

.

Name	
Email	
Company	
Job Title	

* Years of experience:

Number of employees in your campany?

1. Would an online uncertainty assessment tool be useful for organisations that considering adopting Cloud Manufacturing?

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

2. If it is not useful, please explain why:

3. Would an online uncertainty assessment tool be useful for organisations that using Cloud Manufacturing?

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
☐	☐	☐	☐	☐

4. If it is not useful, please explain why:

5. Are the concepts and terminology in online uncertainty assessment tool are consistent?

Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
○	○	○	○	○

6. If not, please explain why:

7. How generalisable the online uncertainty assessment tool is within your industry (Manufacutring)?

8. How generalisable the online uncertainty assessment tool is for other industries?

9. What are the benefits of using online uncertainty assessment tool?

10. What are limitations of using online uncertainty assessment tool?

11. What are the strongest features of online uncertainty assessment tool?

12. What are the weakest features of online uncertainty assessment tool?

13. What are improvements needed for online uncertainty assessment tool?

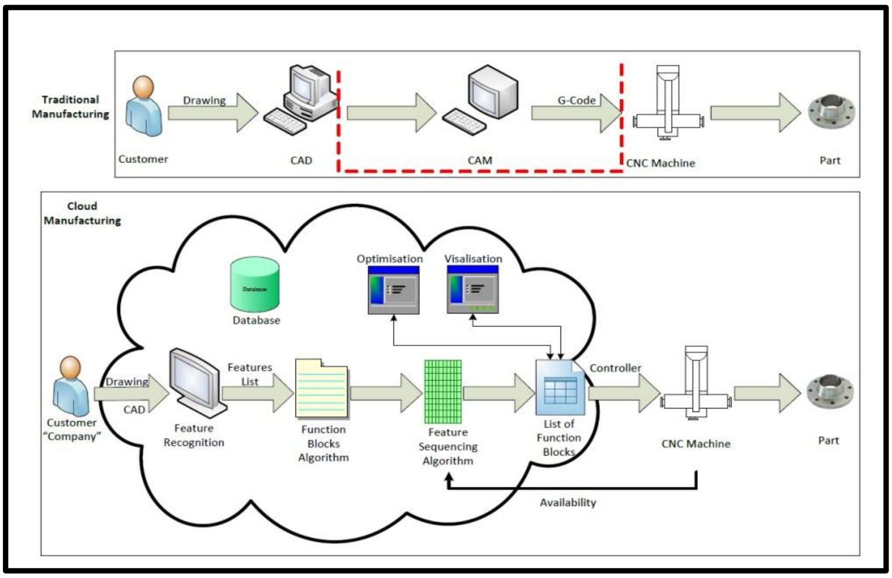
14. Other remarks

Submit

Appendix C Interview Transcript

C.1 Interview Transcript with company X

A sample of interview with manufacturing company X (member of CAPP project) on 24/02/2014, Duration: 1 hour.



Diagram

Q (1): Let me show you a diagram of both traditional manufacturing and Cloud Manufacturing. As you can see in traditional manufacturing, we have the customer's drawing that we transfer it into CAD and CAM systems to generate G-Code for CNC machines. On other hand in Cloud Manufacturing, we are trying to automatic all processes as you can see in the diagram. **My questions here are regarding your company interaction within Cloud Manufacturing in each phase, where how your will deal with different issues such as upload data and download function blocks….Also, what are the problems and considerations in Cloud Manufacturing in each phase?**

Company X: Obviously, from experience of doing it this way, the difficulty will be that we have this moment with this element (refer to diagram: Controller) is the fact the original idea is this will link straight to the controller and most of controller people are not given their information. So, at this point, I think for most people and for most companies, and probably for this project, this probably now meant turn back into G-Code programme. Otherwise, there is no way input into the machine, where the idea originally, this will be a high level. So, is directing the controller, but at the moment, not of the controllers, not of the people that make the controllers are given the information that allows happening. So that is a problem.

Q (2): What about the Visualisation and Optimisation abilities?

Company X: So, you obviously put Visualisation and Optimisation, which you normally get it in standard CAD systems, so I meant this is absolutely important to us.

Q (3): How you would deal with machine availability in Cloud Manufacturing?

Company X: I don't know much about how you planning to integrate this availability cross machines, because that still rely on machine controller, the information been able to embed to the machine controller. So, I don't know how that will work, and at lower level for companies (maybe like SR) I think this have to be manual, some of this has to be manual for machine availability. You have to select the machine that you want to use, rather than have the system to select.

Q (4): In the diagram, you can see Feature Recognition. What are your concerns?

Company X: you absolutely, the wider this generated at the moment is the feature recognition which is a lot of CAD systems used, and we don't found it work at all for us. We gone with "SolidWork" and "SolidCAM" which is not feature recognition based. So, we actually select surfaces and geometry supposed to features. We look at feature CAM which is "DAL CAM" that I believe just does not work for us. We have two CAD systems here, one "ancy" which is low level 4 axis CAD CAM system and we have "SolidWork" and "SolidCAM" which are 5 axis. For us, most of CAD models will be send by customer, most of CAD models we receive are awful, which ended to redesign. So, it make very difficult to, if you trying to receive CAD drawing from.., one of our customers at the moment “Symmetric Medical”, they have one of their apprentice draw a model and they put it as idealist model, but does not read very well when it come in, there are a lot of feature on it that are not recognize the surfaces.

Q (5): So, you need to redesign it again?

Company X: Yes, this is the problem here. Absolutely, we saying CAD drawing but what we originally said was that need to be at the front of it because most of people don’t have CAD system. So, this information must come from somewhere are we generate on here or purely rely on CAD models come in.

Q (6): What about considerations of data, what will be allowed to upload into the Cloud, what type of data you will share?

Company X: Well, it’s difficult one because we little limited to what we can upload because of defence industry staff that we do. So, where we have for UK military or doing work for Brunei, we wouldn’t allow putting most of data on there, it’s difficult for us. We have to put if we looking for, if we want to put a draw in it. We have to take out the features so that can’t be seen. So, it just become purely what we want the machine rather than whole part, which is one issue. The most of information such feed is not a too much of problem.

Q (7): What type of security concerns? Breaches, regulations…

Company X: There are number of issues, IP related to how machine think, where there are IP that we own and I suppose the difficulty is the difference between me and competitive in same, where else is the way of the process and so for most companies they don’t want to share that information. I don’t want another company to understand how quickly the machine, part that already machined because they can compete with me. So, this IP is internal IP and there is external IP. So, my customers dictate, defence customers, I’m not allowed to submit or I’m not allowed to have a drawing goes outside the building on Email. It must go hand copy, it sends by secure mail. So, I can't put that part as CAD model or anything else and put that in for number of reasons. There are other issues with IP to do with materials technologies. A certain materials that we manufacturing here for Royce Rolls supply chain, where the RPI belongs to Royce Rolls, the materials itself. So, I can't give the put in data for those materials into the market because the RPI belongs to Royce Rolls. So, these are the difficult issues.

Q (8): Suppose for example, in Cloud Manufacturing I just give a CAD model and I use Feature Recognition here, I extract one leader feature information, for example, couple of holes and faces. I only use this information; do you fell in that case the copy right related to that part is not protected? I mean all the details are outside the Cloud and just only use one feature in the Cloud. It you will be comfort in using the Cloud at least at some extent?

Company X: I suppose the only when it comes to be an issue if something … As a company you develop a tool and a process for machine feature, one feature in the part, difficult machine materials. Would you then share the information about how the machine that feature. So, it maybe that feature is the only piece of difference between you and another company. And may spend six month trying to find the way to make it to correct tolerance. You find the way to done it; you find the milling tools, a process and a feature. Then it becomes an issue. Also, the biggest issue that will be missing from this is, I think, some level of CAD need to be part of the system in first place, because even companies as our size, many companies don't have CAD at all. You be surprise how many companies don't have any CAD capabilities, even companies earn 3-4 million Ponds, no CAD capabilities at all. They just rely on paper drawing from customers for jobs. I have only one person in my factory that used CAD, everybody else have to program the machine.

Q (9): Is there concerns in how you will share data in the Cloud?

Company X: There is concern over what got shared.

Q (10): What you allowed to be shared?

Company X: This is where to be difficult, as I said, if we doing a military job, we can't upload or share any of it. If we doing a general machining job, absolutely we could. So, I think for a lot of companies, they don't have Cad either, so they can't upload drawing and they need to find other ways to defining what you really need to able to do. If a company has no CAD drawing, you still need to able to select features if you going to use it. So, what really need is a selection of features to be able to almost build using features. So, you really need both of those options. So, you need to be in position, for argument's sake, you have a part shape looks like this and you want to be select the feature and say where is it. You basically say I want to select a pocket, so if you doing this on milling machine; you want to select this pocket. You can build features around simple part, and this probably for low level machining, which probably where will be more value and would work because the low level machining is probably a little RPI issue. Your high level machining where many people will already have their own CAD systems and already have a good quality CAM systems driving all their machines, and those sort of people will not go with this because of they already have in-house process capabilities. So for lower level you already need both of those levels, you can import drawing if the customer sent it to you and select the feature or you can build a feature part, simply while you use the screen.

Q (11): Do you prefer use Cloud Manufacturing platform or your exist platform?

Company X: I still prefer to use my exist platform. Well, I think the issue for the project is if you have ten users and they all putting information in and they all start to use the system properly. What knowledge base it actually creating? Rather been a functional. You put same data and something comes out from other end. Because the whole point of this is we should build a knowledge base from it. So, if you in the position where cutting this material, we should able within the system. The system should looks at it and say the power requirement for the machine, one this, we should able to cut it this way, which this the way how “solidCAM” works. The algorithm workout how much power the machine has available to drive the tool to create the right side. This (refer to Cloud Manufacturing) seek as the same, but the only way to do that is knowledge base. The only way to create a knowledge base is by people putting information in.

Q (12): If you switch to Cloud Manufacturing base inside your company, do you prefer this system (refer to diagram)?

Company X: I think the difficult for the project is, for this to work in a commercial environment, all of these processes need to be own by somebody that release it back. So basically, as a user, I will pay lease to be able to use this (refer to Cloud Manufacturing) as a feature. How this is develop and act as knowledge base. If RPI is return by other person who putting the information in, how is become a knowledge base. The only way for this to be valuable is if it has RPI attached to it because of using a knowledge base from everything coming in to optimize the information coming from the door. So, actually this should able to give you the most optimum way to do things. To do that, you must have a knowledge base. To have a knowledge base to me as a user, to allow the exchange of that information. So, the moment that I say no, you can’t exchange this information and you can’t use as part of knowledge base for the part. This now became pointless. That the difficult of the project has for Commercization.

Q (13): to summarize the problems and considerations in Cloud Manufacturing, I draw a diagram that shows key concerns to your company. Do you have any comments?

Company X: I think that availability, really for most companies, this project gone be target out and will ended to be manual process. I know we trying to do… It’s gone be the users have the availability to select the machine because even if we have the situation where the”Potress” in change of work and we get that feedback, we still not in position of most CNC machines at best R234, gone to switch box, which is usually a manually switch box. It’s most impossible to get data; at least you ride on the top of the food chain in term of manufacturing. At this point, you got open mind, got “SolidCAM” or one of good CAM systems, than its step to be relevant anyway.

Q (14): What else you can add to the diagram?

Company X: In knowledge base, the thing is this need to be…. without the knowledge base, it useless because all of the these computer functions, where is the benefit from use it if is not too when you put your information into the system, there is same experience or knowledge feeding into that, try to give you the best way to produce the part, So that is essential.

Appendix D Fuzzy rules

D.1 Fuzzy rules for Confidentiality Level

1) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = LOW)$
2) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = LOW)$
3) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = MODERATE)$
4) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = LOW)$
5) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = LOW)$
6) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = MODERATE)$
7) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = HIGH)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = MODERATE)$
8) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = HIGH)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = MODERATE)$
9) IF $(Data\ Breach = LOW)$ AND $(Cloud\ Service\ Interfaces = HIGH)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = HIGH)$
10) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = LOW)$
11) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = MODERATE)$
12) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = MODERATE)$
13) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = MODERATE)$
14) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = MODERATE)$
15) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = HIGH)$
16) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = HIGH)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = MODERATE)$
17) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = HIGH)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = MODERATE)$
18) IF $(Data\ Breach = MODERATE)$ AND $(Cloud\ Service\ Interfaces = HIGH)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = HIGH)$
19) IF $(Data\ Breach = HIGH)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = HIGH)$
20) IF $(Data\ Breach = HIGH)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = HIGH)$
21) IF $(Data\ Breach = HIGH)$ AND $(Cloud\ Service\ Interfaces = LOW)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = HIGH)$
22) IF $(Data\ Breach = HIGH)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = LOW)$ THEN$(\ Confidentiality = HIGH)$
23) IF $(Data\ Breach = HIGH)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = MODERATE)$ THEN$(\ Confidentiality = HIGH)$
24) IF $(Data\ Breach = HIGH)$ AND $(Cloud\ Service\ Interfaces = MODERATE)$ AND $(Applications\ Security = HIGH)$ THEN$(\ Confidentiality = HIGH)$

25) IF (Data Breach = HIGH) AND (Cloud Service Interfaces = HIGH) AND (Applications Security = LOW) THEN(Confidentiality = HIGH)
26) IF (Data Breach = HIGH) AND (Cloud Service Interfaces = HIGH) AND (Applications Security = MODERATE) THEN(Confidentiality = HIGH)
27) IF (Data Breach = HIGH) AND (Cloud Service Interfaces = HIGH) AND (Applications Security = HIGH) THEN(Confidentiality = HIGH)

D.2 Fuzzy rules for Availability Level

1) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = LOW) AND (Machine Availability = LOW) THEN(Availability = LOW)
2) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = LOW) AND (Machine Availability = MODERATE) THEN(Availability = LOW)
3) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = LOW) AND (Machine Availability = HIGH) THEN(Availability = LOW)
4) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = MODERATE) AND (Machine Availability = LOW) THEN(Availability = LOW)
5) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = MODERATE) AND (Machine Availability = MODERATE) THEN(Availability = LOW)
6) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = MODERATE) AND (Machine Availability = HIGH) THEN(Availability = MODERATE)
7) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = HIGH) AND (Machine Availability = LOW) THEN(Availability = LOW)
8) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = HIGH) AND (Machine Availability = MODERATE) THEN(Availability = MODERATE)
9) IF (Bandwidth Capacity = LOW) AND (Cloud Service Availability = HIGH) AND (Machine Availability = HIGH) THEN(Availability = MODERATE)
10) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = LOW) AND (Machine Availability = LOW) THEN(Availability = LOW)
11) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = LOW) AND (Machine Availability = MODERATE) THEN(Availability = LOW)
12) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = LOW) AND (Machine Availability = HIGH) THEN(Availability = LOW)
13) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = MODERATE) AND (Machine Availability = LOW) THEN(Availability = MODERATE)
14) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = MODERATE) AND (Machine Availability = MODERATE) THEN(Availability = MODERATE)
15) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = MODERATE) AND (Machine Availability = HIGH) THEN(Availability = HIGH)
16) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = HIGH) AND (Machine Availability = LOW) THEN(Availability = MODERATE)
17) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = HIGH) AND (Machine Availability = MODERATE) THEN(Availability = HIGH)
18) IF (Bandwidth Capacity = MODERATE) AND (Cloud Service Availability = HIGH) AND (Machine Availability = HIGH) THEN(Availability = HIGH)
19) IF (Bandwidth Capacity = HIGH) AND (Cloud Service Availability = LOW) AND (Machine Availability = LOW) THEN(Availability = MODERATE)
20) IF (Bandwidth Capacity = HIGH) AND (Cloud Service Availability = LOW) AND (Machine Availability = MODERATE) THEN(Availability = MODERATE)
21) IF (Bandwidth Capacity = HIGH) AND (Cloud Service Availability = LOW) AND (Machine Availability = HIGH) THEN(Availability = MODERATE)

22) $IF\ (Bandwidth\ Capacity\ = HIGH)\ AND\ (Cloud\ Service\ Availability\ = MODERATE)\ AND\ (Machine\ Availability\ = LOW)\ THEN(\ Availability = HIGH)$
23) $IF\ (Bandwidth\ Capacity\ = HIGH)\ AND\ (Cloud\ Service\ Availability\ = MODERATE)\ AND\ (Machine\ Availability\ = MODERATE)\ THEN(\ Availability = HIGH)$
24) $IF\ (Bandwidth\ Capacity\ = HIGH)\ AND\ (Cloud\ Service\ Availability\ = MODERATE)\ AND\ (Machine\ Availability\ = HIGH)\ THEN(\ Availability = HIGH)$
25) $IF\ (Bandwidth\ Capacity\ = HIGH)\ AND\ (Cloud\ Service\ Availability\ = HIGH)\ AND\ (Machine\ Availability\ = LOW)\ THEN(\ Availability = HIGH)$
26) $IF\ (Bandwidth\ Capacity\ = HIGH)\ AND\ (Cloud\ Service\ Availability\ = HIGH)\ AND\ (Machine\ Availability\ = MODERATE)\ THEN(Availability = HIGH)$
27) $IF\ (Bandwidth\ Capacity\ = HIGH)\ AND\ (Cloud\ Service\ Availability\ = HIGH)\ AND\ (Machine\ Availability\ = HIGH)\ THEN(Availability = HIGH)$

D.3 Fuzzy rules for Integrity Level

1) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = LOW)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = LOW)\ THEN(\ Integrity = LOW)$
2) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = LOW)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = MODERATE)\ THEN(\ Integrity = LOW)$
3) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = LOW)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = HIGH)\ THEN(\ Integrity = LOW)$
4) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = MODERATE)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = LOW)\ THEN(\ Integrity = LOW)$
5) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = MODERATE)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = MODERATE)\ THEN(\ Integrity = MODERATE)$
6) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = MODERATE)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = HIGH)\ THEN(\ Integrity = MODERATE)$
7) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = HIGH)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = LOW)\ THEN(\ Integrity = LOW)$
8) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = HIGH)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = MODERATE)\ THEN(\ Integrity = MODERATE)$
9) $IF\ (Data\ Control = LOW)\ AND\ (Remotely\ Access\ Cloud\ Services\ = HIGH)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = HIGH)\ THEN(\ Integrity = MODERATE)$
10) $IF\ (Data\ Control = MODERATE)\ AND\ (Remotely\ Access\ Cloud\ Services\ = LOW)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = LOW)\ THEN(\ Integrity = LOW)$
11) $IF\ (Data\ Control = MODERATE)\ AND\ (Remotely\ Access\ Cloud\ Services\ = LOW)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = MODERATE)\ THEN(\ Integrity = MODERATE)$
12) $IF\ (Data\ Control = MODERATE)\ AND\ (Remotely\ Access\ Cloud\ Services\ = LOW)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = HIGH)\ THEN(\ Integrity = MODERATE)$
13) $IF\ (Data\ Control = MODERATE)\ AND\ (Remotely\ Access\ Cloud\ Services\ = MODERATE)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = LOW)\ THEN(\ Integrity = MODERATE)$
14) $IF\ (Data\ Control = MODERATE)\ AND\ (Remotely\ Access\ Cloud\ Services\ = MODERATE)\ AND\ (Cloud\ services\ interfaces\ data\ transmission\ = MODERATE)\ THEN(\ Integrity = MODERATE)$

15) IF (Data Control = MODERATE) AND (Remotely Access Cloud Services = MODERATE) AND (Cloud services interfaces data transmission = HIGH) THEN(Integrity = MODERATE)
16) IF (Data Control = MODERATE) AND (Remotely Access Cloud Services = HIGH) AND (Cloud services interfaces data transmission = LOW) THEN(Integrity = MODERATE)
17) IF (Data Control = MODERATE) AND (Remotely Access Cloud Services = HIGH) AND (Cloud services interfaces data transmission = MODERATE) THEN(Integrity = HIGH)
18) IF (Data Control = MODERATE) AND (Remotely Access Cloud Services = HIGH) AND (Cloud services interfaces data transmission = HIGH) THEN(Integrity = HIGH)
19) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = LOW) AND (Cloud services interfaces data transmission = LOW) THEN(Integrity = MODERATE)
20) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = LOW) AND (Cloud services interfaces data transmission = MODERATE) THEN(Integrity = MODERATE)
21) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = LOW) AND (Cloud services interfaces data transmission = HIGH) THEN(Integrity = HIGH)
22) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = MODERATE) AND (Cloud services interfaces data transmission = LOW) THEN(Integrity = HIGH)
23) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = MODERATE) AND (Cloud services interfaces data transmission = MODERATE) THEN(Integrity = HIGH)
24) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = MODERATE) AND (Cloud services interfaces data transmission = HIGH) THEN(Integrity = HIGH)
25) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = HIGH) AND (Cloud services interfaces data transmission = LOW) THEN(Integrity = HIGH)
26) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = HIGH) AND (Cloud services interfaces data transmission = MODERATE) THEN(Integrity = HIGH)
27) IF (Data Control = HIGH) AND (Remotely Access Cloud Services = HIGH) AND (Cloud services interfaces data transmission = HIGH) THEN(Integrity = HIGH)